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ABSTRACT

This module discusses the characteristics of alternate sites and management schemes and attempts to evaluate the efficiency of each alternative in terms of waste treatment. Three types of non-crop land application are discussed: (1) forest lands; (2) park and recreational application; and (3) land reclamation in surface or strip mined areas. (BB)

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Land Application of Wastes

An Educational Program

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
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NON-CROP AND FOREST SYSTEMS

Module 13

January, 1978

SE 025 027

LAND APPLICATION OF WASTES - AN EDUCATIONAL PROGRAM

The objective of this program is to increase the knowledge of engineers, scientists, waste management specialists and other practitioners in the concepts and principles needed to properly utilize the potential of land for the application of wastes. It is designed for individuals concerned with waste disposal alternatives for municipal, industrial, and agricultural wastes. The modules in this Program incorporate knowledge from sanitary and environmental engineering, agronomy, soil science, agricultural engineering, economics, and law.

The program consists of some twenty-five modules and audio-visual materials as appropriate.

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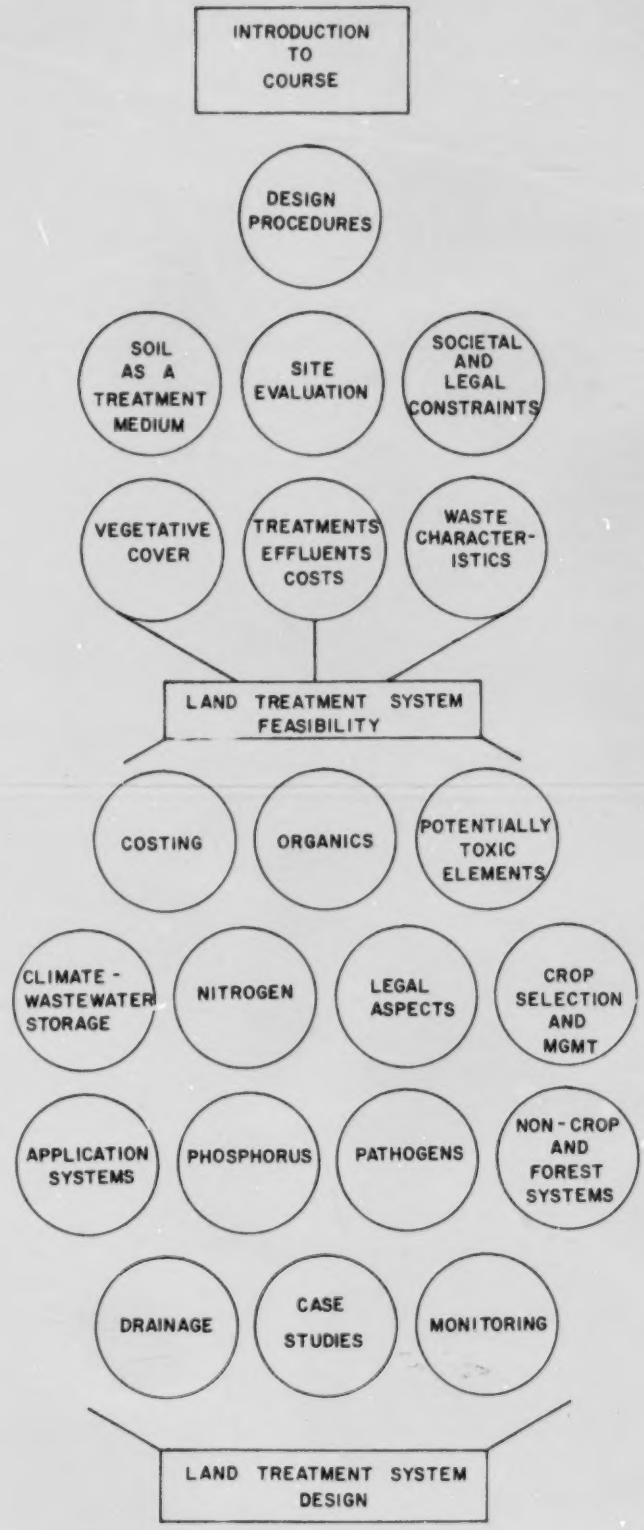

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NON-CROP AND FOREST SYSTEMS

Module 13

January, 1978

Summary

Although agricultural land is most often utilized for land application of wastes, an alternative site may be necessary because agricultural land is unavailable or too expensive. Forest land may be the only choice in some regions because of its proximity, its abundance, and its lower price tag. The needs of the community may determine the choice of a land treatment site. Citizens may desire more open space, such as green belts, parks, or golf courses. Especially in arid regions, there may be pressure to irrigate these areas with reclaimed wastewater. Some cities have used reclaimed wastewater of high quality for swimming. Another alternative is to manage the land treatment site as a wildlife habitat, thereby increasing public acceptance.

Still another community demand may be to use wastewater and sludge to reclaim surface or strip mined areas. Reclamation would usually result in the area being restored to natural vegetation conditions, although it may be possible in some cases to establish agriculturally productive land.

This module discusses the characteristics of alternate sites and management schemes and attempts to evaluate the efficiency of each alternative in terms of waste treatment. Following the breakdown of alternatives listed above, this module is divided into three distinct sections: Forest Lands, Park and Recreational Applications, and Land Reclamation and Revegetation.

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Objectives

After completing this module the reader should be able to:

1. Describe the characteristics of forest land which favor and disfavor it as a land treatment site.
2. List the different options for managing forest land used for a waste application site.
3. Describe how wastewater can be used to create and enhance recreation sites.
4. Describe the chemical and physical characteristics of mine spoil material and how it can be amended with the addition of sludge and/or wastewater.
5. Describe one study which experimented with adding sludge and/or wastewater to former mining areas, specifying the results of such additions.

Introduction

EPA (1975) broadly classified crops as follows: Perennials (forage and fruit crops), Annuals (field crops and vegetables), Landscape Vegetation (including parks and golf courses), and Forestland. The latter two "crops", along with reclamation of mine spoils, are discussed in this module.

A major limitation to the cropping alternatives discussed in Module 20, "Crop Selection", is that in most places the land most suitable for large scale field operations is already in active agriculture. The price of this land has increased steadily in recent years, to the point where it may no longer be possible to pay for land with the crops produced. Furthermore, as land pressures intensify, farmers may strongly resist any transfer of large land tracts from private to public ownership.

Most farmers could benefit from improved drainage and an assured adequate supply of moisture. These benefits, however, would be least on the best agricultural lands. Benefits are potentially greatest on sites where a few severe limitations can be overcome at an otherwise manageable location. Such was the situation in Muskegon County, Michigan, where barren, excessively well drained sandy soils were available nearby at low cost. In many situations, such sites may not be available.

In some areas, the possiblity of reclaiming coal mine spoil and acid wastes may preclude any thought of alternate management schemes. In mountainous areas forests may be the only areas available for land application. Forest lands are usually much less expensive than croplands, and as discussed below, may be managed effectively if not overloaded. In urban/suburban areas, parks and golf courses may be the only open areas available for wastewater irrigation. In such situations, the creation of ad-

ditional green belts in outlying areas may be desirable for more than one reason.

An assessment of a community's economic base and demography is important in predicting its future growth needs. A community where there are many young families with small children will need more playground space than a community of older persons. This older community would probably be more interested in preserving open space in the form of golf courses, parks for sitting and walking, or forest preserves near urban centers. If a community was established in the earlier part of the century, it probably was not designed to incorporate open space. Such a community would thus be a candidate for the expansion or creation of open space for its inhabitants. Newer communities may already have established open space. Possibly, wastewater could be used to irrigate these existing open spaces, saving the municipality the cost of irrigating with fresh water, while treating its wastewater. A community may be located in a historic area, and may wish to preserve or enhance historic buildings, paths, and so on. Care must be taken in designing for the land application site that these areas of natural or historic interest not be disturbed.

EPA has recently noted (Bastian and Whittington, 1977) that land application of sludge remains a controversial issue among researchers primarily because of possible effects upon increasing cadmium in the human food chain. The use of sludges in non-food chain crop production, such as the options outlined in this module, as well as the sod and nursery production options mentioned in Module 20, "Crop Selection and Management Alternatives", allow the recovery of the nutrients and soil building value of municipal wastes while minimizing risks. Being able to avoid controversy among experts on this issue may

help to settle the fears of the public over waste pathogens and toxic substances.

Forest Lands

Forest lands prove useful as land application sites. Besides being relatively inexpensive, they are abundant, occupying more than 33% of the total land area in the U.S.

Forest soils have high infiltration/percolation

Undisturbed forest soils are superior in minimizing surface runoff if the underlying soil is not saturated. Infiltration rates often exceed 6 inches/hour. This is largely due to high macroporosity of the upper mineral soil and its protection by vegetation and surface litter against the impact of water drops. The litter layer also furnishes food for organisms which permeate the soil and maintain favorable conditions for water entry. In fact, if the forest floor remains in a relatively undisturbed state, infiltration rates continue high even when the overhead canopy is removed. Disruption of the surface, however, by trampling and compaction from human acitivity, livestock, or machinery decreases infiltration markedly and may lead to surface runoff.

Undisturbed forest soils have a high rate of infiltration and percolation.

The initial phases of wastewater application at a food processing facility in New Jersey demonstrated how great the differences between forest and cropland may be: On a cultivated field, 2 inches of wastewater per day produced soil saturation and considerable surface runoff; in a hardwood forest some 400 feet away on the same soil, over 150 inches were applied during a 10-day period without noticeable saturation or surface runoff (Mather, 1953). This and many less dramatic examples establish the high acceptance rate for water by forest soils. But they also emphasize a related consideration, that is, the ultimate destiny of the applied water.

Because of high infiltration capabilities, forest lands are particularly suited to year-around applica-

tion of wastewater. Due to the insulating properties of the forest floor, soil frost may not even form. Even where soil freezing does occur, it is often of the "honeycomb" type, which maintains a high porosity (Trimble et al., 1958). Waste renovation, however, requires more than just infiltration. Suspended and dissolved waste constituents must also be considered.

Forest soil limited by its drainage potential

Despite excellent infiltration capacities, forest lands may be limited by the ultimate fate of applied water and nutrients. These constraints may require lower loading rates on forest lands than on croplands. Unlike agricultural lands, it is unlikely that extensive underdrainage will be undertaken due to difficulties which would be encountered with excavation work in trees, undergrowth, and roots. It is, therefore, very important that a site be naturally well drained or that water applications be limited to little more than potential evapotranspiration (ET_p) demands.

Unamended forest land may be poorly drained compared to agricultural land.

Due to this perennial growth habit and well developed root system and canopy structure, a forest community should have ET_p demand greater than most crops. As with crop irrigation, ponding of water on the soil surface must be avoided if growth, nutrient uptake, and transpiration are to be maximized and nuisances avoided. If water tables are maintained too close to the surface, trees will develop a shallow rooting habit and be subject to toppling by the wind. For this reason Sopper and Kardos (1973) recommended that non-irrigated buffer zones of 50-100 feet be left on the windward side of any irrigated forest area to act as a windbreak.

Tree species differ in tolerance to water

Tables 1 and 2 present some information on the tolerance of a few tree species to high water tables

TABLE 1. Correlation of the ground water table with the composition and growth of forest vegetation in Wisconsin.

Depth to ground water, feet	Composition of forest stand	Est. yield at 100 years cu. ft.
	A. Podsol region, silty clay loams derived from granitie drift	
1 - 1.5	Balsam fir, white spruce, some black ash and red maple. Understory of mountain ash, tag alder, willows and dogwood	2,200
2.0 - 3.0	Hard maple, rock elm, red maple, some basswood, yellow birch, balsam fir and white spruce. Hard maple and basswood inferior.	3,500
4.0 - 5.0	Hard maple, basswood, some white pine. Leatherwood and numerous other shrubs. Vigorous growth of sprouts.	4,800
	B. Prairie - Forest Region. Silt loams derived from calcareous drift	
0.7 - 1.2	Lowland Meadow	--
2.0 - 3.0	Bur oak, black oak, some red oak, aspen and box elder. Abundant walnut in understory.	1,900
4.0 - 5.0	White oak; red oak, some black oak, walnut, hickory, white ash	3,200

Source: Van't Woudt and Hagan, (1957).

TABLE 2. Tolerance of various trees and shrubs to flooded soil in the Upper Mississippi Basin.

Species	Years Survived	Remarks
Sand bar willow	2	Mostly dead in last year
River birch	2	Survived well 1st year
Cottonwood	2	Survived well 1st year
Silver maple	3	Mostly dead in 2nd year
Elm	3	Mostly dead in 2nd year
Hackberry	3	Fair growth in 2nd year
Red oak	3	Scarce in bottoms
Bur oak	3	Mostly dead in 2nd year
Swamp white oak	3	Fair growth 2nd year
Pin oak	3	Mostly on higher ground
Alder	3	Hardy to second year
Green ash	4	Hardy 2nd year, fair in 3rd
Black willow	4	Hardy to 3rd, all died 4th
Deciduous holly		Hardy to 4th year
Swamp privet		Hardy to 4th year
Buttonbush		Hardy after 4 years
Red osier dogwood		Hardy after 7 years

Source: Van't Woudt and Hagan, (1957).

and flooding. Note that, as with forage species, the shallow rooted species often found in moist soils are not necessarily the most tolerant to flooding. The tolerance of different forest species to salts and toxic elements is not well documented but variation may be expected. Red Pine appears to be sensitive to boron (Sutherland et al. 1974). A Pennsylvania study indicated that among the seedlings of 8 coniferous tree species, European and Japanese Larch and White Pine responded best to irrigation with sewage effluent (Table 3).

Forests are commonly located on steep rocky hillsides where soils are often shallow and imperfectly drained. Water applied on a hillside may move laterally within the soil. This may increase soil contact and improve treatment efficiencies. This water, however, may emerge at localized spots downslope, and drainage must be provided from these locations or a manageable pond or marsh created.

Forest soil limited in nitrogen uptake

Nitrogen loading is often the limiting factor in using forest lands for waste treatment sites.

Aside from the ability of a site to drain itself naturally, the fate of added nutrients, particularly nitrogen, is a major constraint in the use of forest land for waste application, regardless of season. To understand this constraint requires some familiarity with normal nutrient relations in unamended forest systems.

Natural forest communities have adapted to relatively infertile soil conditions through efficient nutrient cycling mechanisms. Recent work (Switzer and Nelson 1972; Bormann, Likens and Melillo 1977) has shown considerable internal recycling of nutrients. Prior to leaf fall, considerable nitrogen is translocated from the leaves to woody tissue. The annual uptake of nutrients compares with certain agronomic crops but only a small percentage of this is ever removed from the area. Nutrient rich leaves,

TABLE 3. Total height growth of surviving tree seedlings during the period 1965 to 1970

Species	Irrigated plots		Control plots	
	Survival	Height	Survival	Height
	%	feet	%	feet
European larch	23	8.7	0	-
Japanese larch	17	8.4	0	-
White pine	70	6.3	17	2.6
Red pine	40	5.4	20	2.0
White spruce	30	4.3	3	2.8
Pitch pine	3	3.8	3	1.4
Austrian pine	13	3.6	13	2.1
Norway spruce	47	3.6	7	1.6

Source: Sopper and Kardos (1973)

twigs, bark, and roots are returned to the soil rather than being hauled away in harvests.

These materials remain on or in the soil until decomposition again renders the nutrients available for plant uptake. Small natural losses from the system are essentially balanced by small natural inputs. At any given time, the majority of nutrients are tied up in the forest floor or in the soil organic matter. Figure 1 depicts the distribution and annual cycling of nitrogen in an oak-hickory forest in Tennessee.

A further consideration is the changing pattern of nutrient retention with time. Forests do not have uniform nutrient requirements throughout their lifespans. As shown in Figure 2, annual nutrient retention in the plant tissue increases up to some maximum during the early life of a new forest stand. Beyond this point, annual retention decreases so that at great age, no further net accumulation of nutrients occurs from one year to the next. The actual point of maximum nutrient accumulation varies among species. For example, loblolly pine, a common species in the Southeast, achieves maximum accumulation for all macronutirents (N, P, Ca, Mg, K, S) during the first 30 years, with much of this being concentrated in the initial 10 years of growth (Switzer et al. 1968; Switzer and Nelson 1972). By age 45, nutrition in a well nourished loblolly pine stand is largely a matter of cycling, with little or no net accumulation. Hardwood species such as birch, maple, and oak have somewhat longer periods of nutrient accumulation, although the overall trends remain as shown in Figure 2.

Young stands of trees take up nutrients to a greater degree than mature stands.

Harvest of wood crops removes accumulated nutrients from the forest site, much as with an agronomic crop. The amounts removed, however, are generally low when averaged over the time required for accumulation. Table 4 compares harvest removals and

Although harvesting wood removes accumulated nutrients, the long periods between tree harvests makes nutrient removal small when compared with corn.

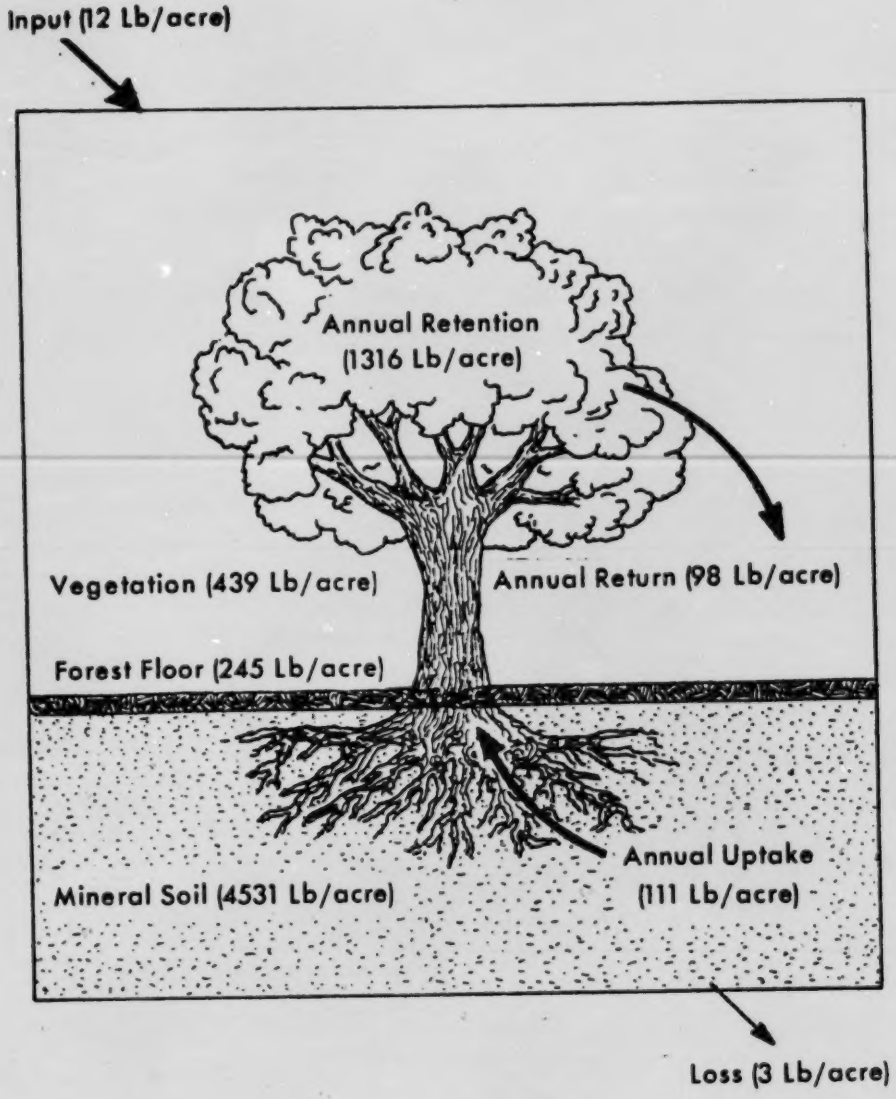


Figure 1. Within natural forest systems, most nitrogen is tied up in the mineral soil, with lesser amounts in the forest floor and the vegetation. Annual cycling of nitrogen means that only a small portion of the annual uptake is actually retained in the plant tissue. In this study, measured atmospheric input exceeds leaching loss. Additional gains from N fixation and losses through denitrification are likely but the amounts are unknown (after Henderson and Harris 1975).

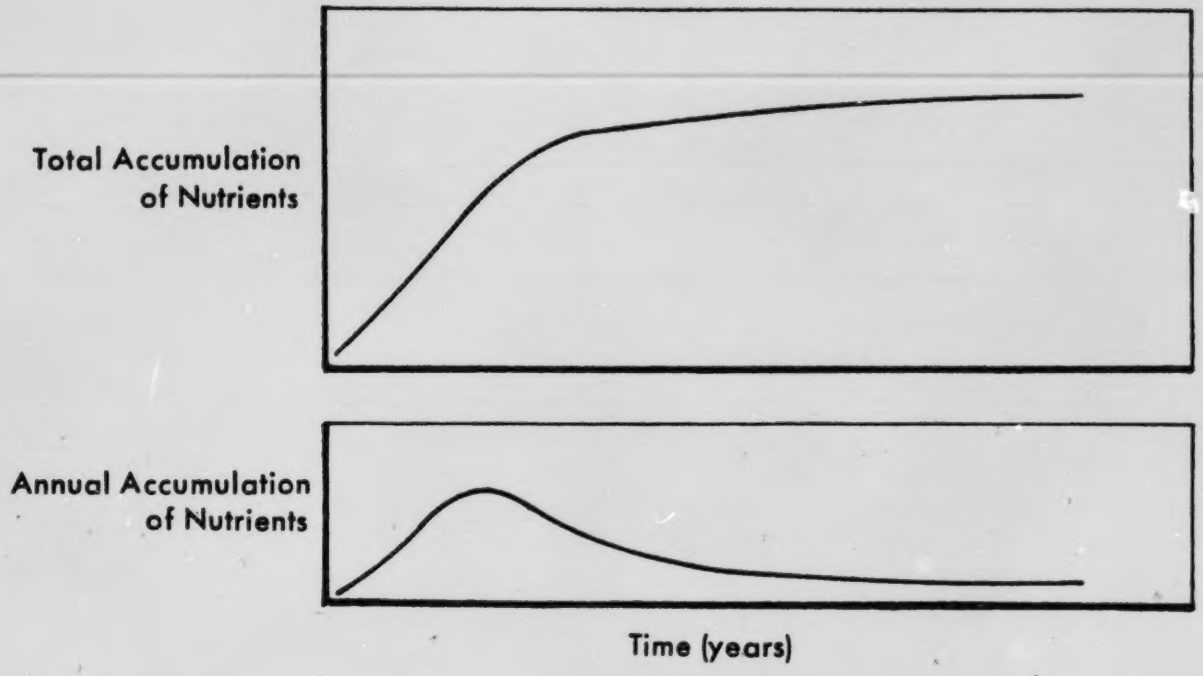


FIGURE 2. The annual accumulation of nutrients in forest stands varies with age. Higher rates of annual accumulation occur in younger stands; in old-growth stands, mortality offsets growth and net accumulation approaches zero (after Tamm et al. 1974).

TABLE 4 Comparative nutrient removal by two forest species and corn.

	Nutrient removal through harvest		Ave. annual nutrient removal from site	
	lb/acre		lb/acre-yr	
	N	P	N	P
Corn				
Annual harvest (16 years)	1600	288	100	18
Annual harvest (30 years)	3000	540	100	18
Loblolly Pine, age 16 years				
Whole tree (above ground)	227	27	14.2	1.7
Debarked pulpwood[1]	66	12	4.1	.8
Aspen, age 30 years				
Whole tree (above ground)	170	25	5.7	.8

[1] includes only stemwood to 3-inch top with bark removed
Source: Jorgensen et al. 1975; Boyle 1975.

annual accumulations of two short rotation forest crops with corn.

Forests can be altered to enhance waste treatment

Waste renovation on forest land might be promoted by replacing native trees with species better suited to specific application schemes. For example, hardwoods in general accumulate greater amounts of nitrogen and other elements than conifers. Young stands retain a greater proportion of the annual uptake than do older trees.

On-going studies on forest land indicate that tree species may be planted and managed so as to increase nutrient uptake, making it comparable to the uptake of corn.

European investigators are studying irrigation of poplar plantations for the dual purposes of wood production and wastewater renovation. This option could become attractive within a few years if current experiments on whole tree removal and ultra-short rotations prove economically feasible. Fast growing hardwood species such as sycamore, hybrid poplars, and cottonwood may be harvested by some version of a silage chopper, and then regenerated by coppicing, that is by rapid sprouting from established root systems (Boyle, 1975; Herrick and Brown, [illegible]7). This management technique maximized production of pulp fiber. Limited data indicate that such short rotations can provide nutrient uptake comparable to corn (Urie, 1975). Despite these intensive management options, the data in Table 4 indicate a basic limitation in the capability of traditional forest crops to remove added nutrients. This emphasizes the importance of the soil itself in retaining waste constituents, and as a site for other renovation mechanisms such as denitrification.

Forest soils take up considerable phosphorus

Phosphorus is tightly bound as iron and aluminum compounds in most acid forest soils. Soil analyses from a mixed conifer forest in California indicate that up to 1400 lb P/acre could be held in the surface

Many forest soils are capable of handling high loadings of phosphorus.

6 inches and still maintain a soluble phosphorus concentration of less than 0.20 ppm (Powers et al., 1975). Total phosphorus retention, of course, is strongly related to soil depth, with deeper soils capable of binding more total phosphorus, all other factors being equal. Resting periods between applications increase P retention, as explained in Module 19, "Phosphorus Considerations". An exception occurs in certain highly weathered sands where low iron and aluminum levels preclude appreciable phosphorus retention (Ballard and Fiskell, 1973).

Forest soils remove nitrogen through nitrification-denitrification

Adsorption of ammonium ions on soil colloids and fixation by soil organic matter can remove large amounts of nitrogen from applied effluent. The soil's ability to remove ammonium depends upon the amount of competing (primarily divalent) cations contained in the soil and in the applied wastewater. Lance (1972) has reviewed a method of estimating this, and using his method, if a typical effluent containing 25 ppm NH_4^+ - N, 25 ppm Ca^{++} and 20 ppm Mg^{++} were applied, ammonium would be adsorbed up to about 10% of the CEC. A potentially much greater amount of ammonia nitrogen may be fixed by soil organic matter, especially under alkaline conditions.

The fate of adsorbed ammonia -N is to be nitrified by soil microorganisms. Following nitrification, percolating waters may carry a pulse of high nitrate water which, if not managed, may degrade ground waters. The rate of nitrification is dependent upon temperature, moisture, pH and other factors which are not fully understood. Nitrification has generally been found to be very slow during the winter, and often maximum nitrate concentrations, resulting from the mineralization of added manure, are not observed in soils until summer. This, however, may be influenced by the type of plant community. Woodwell

Nitrification in forest soils depends on temperature, moisture, and perhaps the type of plant community.

et al. (1974) at Brookhaven, New York observed nitrification (and nitrate leaching) to continue during the winter under a late successional hardwood forest, but not under red pine, abandoned field, or timothy ground covers.

Whether denitrification is significant in waste amended forest soils has not yet been determined. Studies of this point are currently in progress (Nutter et al., 1975; Schultz et al., 1975). The process of denitrification requires the presence of both nitrate and decomposable organic substances under anaerobic conditions. Nitrate is seldom abundant in natural forest soils, although specific conditions governing nitrate formation are not fully understood. Acid conditions apparently retard nitrification but commonly do not prevent it. The primary control in nitrate production may be simply the supply of ammonium ions. In unamended forest soils, the small amounts of available ammonium contributed by precipitation inputs or mineralization of organic nitrogen are quickly utilized by plant roots and microorganisms. Populations of nitrifying bacteria are, therefore, often small. An influx of ammonium in wastewater additions, however, would likely result in population changes and lead to increased nitrification. If so, the fresh carbon provided by annual litter fall and root turnover, together with periodic anaerobic conditions caused by heavy wastewater applications, makes denitrification look promising as a nitrogen renovation mechanism.

On-going studies indicate that denitrification may be a major nitrogen renovation mechanism in wastewater amended forest soils.

Careful scheduling of wetting and drying may be used to create periodic cycles of aerobic and anaerobic conditions and so promote nitrification-denitrification reactions in the soil. The same technique should also increase phosphorus retention by allowing for reversion reactions between applications. A study is now in progress in Georgia to

develop design guidelines for waste application on steep forested slopes. It is hoped that periodic saturation of soil at the base of the slope, caused by subsurface lateral flow, will result in denitrification (Nutter et al., 1975).

Studies show low rate of mature forest nitrogen removal compared to herbaceous vegetation

Work with the "Living Filter" land application system (Hook and Kardos, 1976) has demonstrated that a growth of sparce white spruce and dense annual herbage ("Old Field Site") on a clay loam soil treated with 2" effluent/week from April through November had a much greater nitrogen removal efficiency, presumably due to denitrification or organic matter accumulation, than did a mature hardwood community ("New Gameland Site") on a sandy loam soil treated with 2"/week year around. Nitrate concentrations under the hardwood community were consistently greater than 10 ppm suggesting again that nitrification continued year around. When a previosuly untreated hardwood plot adjacent to the "new gameland" site was irrigated identically with that site, using an oxidized effluent, steady state conditions with essentially zero renovation were established within 18 months.

A red pine plantation on the same soil and receiving the same treatment as the "old field" site had an average nitrate nitrogen concentration of 24.2 ppm at the 120 cm depth in the year preceding clear cutting. Following clear cutting, when volunteer herbaceous vegetation became established, nitrate nitrogen concentrations at the 120 cm depth dropped to an average of 8.3 ppm the first year and 3.8 ppm the second year. Thus, regardless of the mechanism, herbaceous vegetation appears to be effective, at least in the short run, in preventing nitrate leaching. Table 5 indicates the changes in predominant herbaceous species which occurred at the "old field"

Herbaceous vegetation at the forest site seems to prevent nitrate leaching to groundwater.

TABLE 5. Predominant herbaceous vegetation species on the irrigated and control plots of the white spruce area in 1972

Species	Irrigated Plot		Control Plot	
	Percent Cover	Average height	Percent Cover	Average height
	%	feet	%	feet
Goldenrod (Solidago juncea)	<1	2.8	5	1.8
Aster (Aster spp.)	0	-	5	1.1
Dewberry (Rubus flagellaris)	0	-	40	0.8
Strawberry (Fragaria vesca)	<5	0.9	10	0.5
Poverty grass (Danthonia spicata)	0	-	20	0.3
Everlasting (Antennaria spicata)	0	-	5	0.1
Goldenrod (S. rugosa, S. graminifolia, S. juncea)	<5	5.3	0	-
Milkweed (Asclepias rubra)	<5	5.1	0	-
Indian hemp (Apocynum cannabinum)	<5	3.3	0	-
Night shade (Solanum dulcamara)	10	2.3	0	-
Clearweed (Pilea pumila)	75	1.5	0	-

Source: Sopper & Kardos (1973)

site as a result of 19 years of irrigation.

If it is determined that increased litter accumulation is the major mechanism responsible for nitrogen removal in "old field" type situations, then some form of litter removal could be adopted to prevent eventual nutrient recycling from the nitrogen-rich litter and resultant leaching to groundwater.

In certain types of forests, periodic "controlled" burns might be used to remove a portion of the surface organic debris during this period of accumulation. In the process, much of the nitrogen would be volatilized. The techniques are available because prescribed fire is already used in Southeastern pine forests for fuel reduction, game management and site preparation, and in the West for fuel reduction (to reduce the danger of wildfire).

Nitrogen can be removed from forest land by periodic controlled burning in which N is volatilized.

Applications of wastewater contaminated with cadmium or mercury should perhaps not be made to acid forest soils. Munro et al. (1977) concluded that "solubility limits and leaching of heavy metals from forest floor litter is a significant process in the movement of these metals (Pb, Cd, Zn, and Cu) through a forested watershed." Solubility of these metals increases as pH goes down.

Success of Forest Sites Varies

Like other plant communities, forests are a product of both genetic and environmental factors. The potentials for growth, development, and survival are controlled by inherent genetic properties, whereas environmental conditions determine the degree to which these potentials are realized. Environmental changes, such as additions of water and nutrients, can alter the performance of individuals and, eventually, the overall species composition of the site. An important point is that some alteration in vegetation is inevitable, and the more accurately the change

Very few forest waste application sites have been studied and monitored to determine long-term effects.

can be predicted, the more likely that specific management objectives can be achieved. Few waste application projects allow analysis of long term effects and thus predictions are largely speculative. Results from three application systems, however, illustrate some of the effects and management difficulties to be considered:

1) Seabrook Farms, a vegetable processing facility at Seabrook, New Jersey generates up to 12 million gallons of wastewater per day. This wastewater has been applied to a 70 to 84 acre woodland area since 1950. The effect of such applications is particularly striking due to the small area involved. Essentially, an oak-hickory forest type has been transformed into a near-swamp community. The original trees and associated undergrowth were either destroyed by the high pressure nozzle jets or were unable to withstand the increased moisture regime. These have died and been replaced with dense stands of water-tolerant grasses (up to 6 feet tall), vines, shrubs, and herbs (Stevens 1972).

The changes in soil and vegetation characteristics after the first seven years of operation with from 400-600 inches of wastewater applied each season are shown in Figure 3.

As the graphs indicate, changes in both soil and vegetation have been major. Despite the dieback of much of the native cover, however, the hydrologic capacity of the forest floor has been maintained. Another survey (Stevens 1972) identifies impacts on nearby woodlands outside the immediate application area. Here accumulations of water in shallow ponds and resulting dieback of trees indicate that seepage at lower depths is a continuing effect. As of 1977, the Seabrook Farms woodland irrigation system has been discontinued. Changes in plant operation have resulted in greatly reduced flows,

Although the site was changed from an oak-hickory forest to a swamp, Seabrook Farms obtained a high degree of wastewater purification and a high rate of infiltration/percolation for more than 20 years.

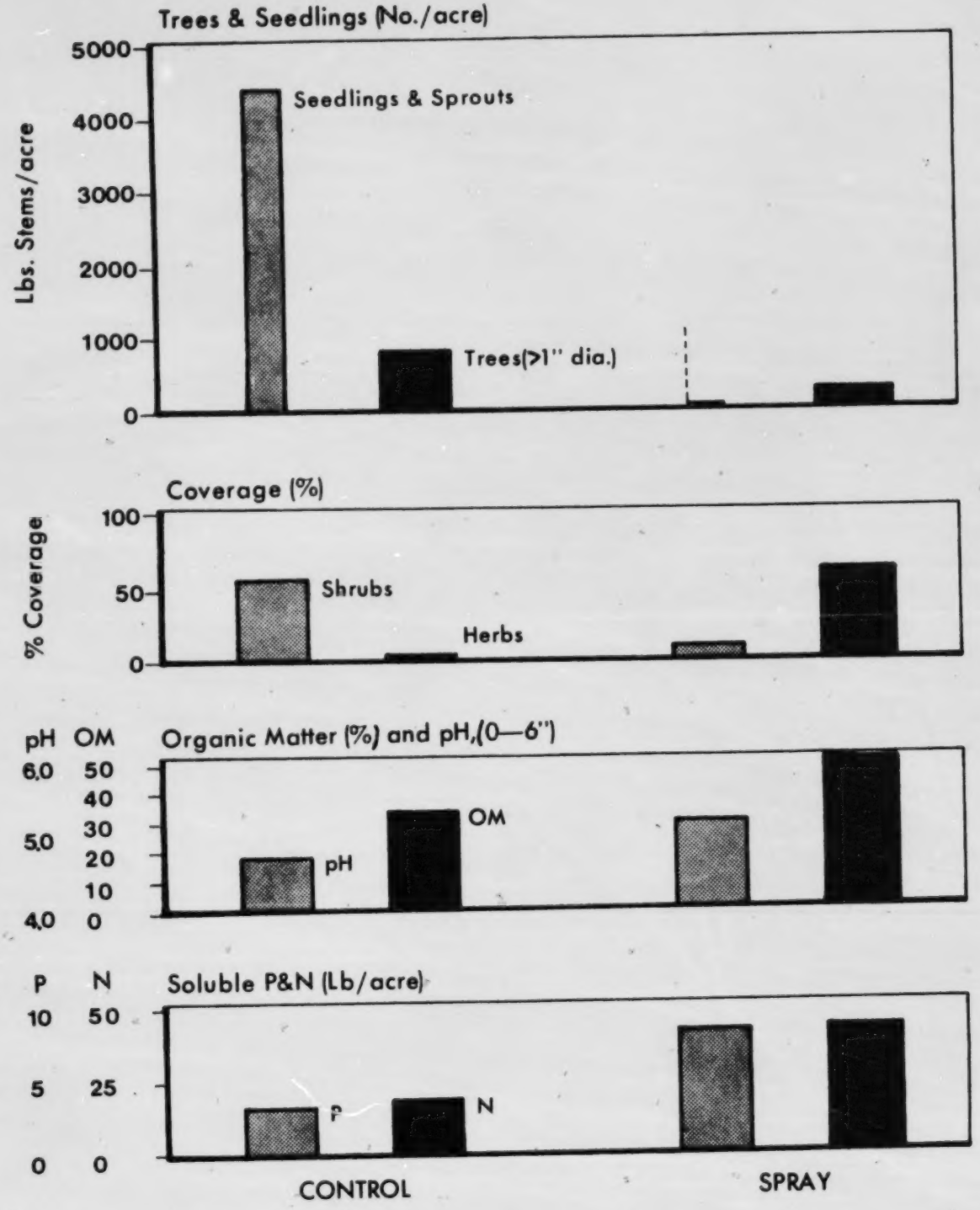


Figure 3. Changes in soil and vegetative characteristics at Seabrook Farms as a result of spray irrigation.

which are now treated in a lagoon made up of part of the old system.

2) In 1953, the Gerber Products Co. of Fremont, Michigan planted four species of trees as part of a cannery wastewater application study. Seedlings of boxelder (Acer negundo) and cottonwood (Populus deltoides) and unrooted cuttings of black willow (Salix nigra) and balsam poplar (Populus balsamifera) were used. Wastewater was applied at a rate of 2 in./week for 24 to 32 weeks (Approximately April-October). Table 6 gives the results after three years.

TABLE 6. Survival and growth of forest species under irrigation with cannery wastewater

Tree Species	Survival (%)		Ave. Height Growth (ft)	
	Control	Irrigated	Control	Irrigated
Boxelder	5.6	11.5	1.5	3.4
Cottonwood	7.0	0.1	1.0	6.0
Black Willow	15.5	58.3	1.5	9.0
Balsam Poplar	-	0.4	-	5.0

Source: Rudolph, 1957.

Surviving trees of all species grew much better in the irrigated soil as compared to the control. Winter-killing appears to have been a major factor in the low survival of cottonwood trees. The abundant soil moisture available late in the growing season together with added nitrogen probably delayed normal hardening of the plant tissues in the fall season (Rudolph and Dils, 1955). But another cause of over-winter kill was mouse damage. Summer irrigation promoted a heavy growth of grasses around the trees which, combined with snow, provided excellent rodent harborage. Mice killed many trees by complete removal of bark from the lower stem (Fisk, 1964). Sub-

sequent year-round spraying on these sites eventually eliminated all trees through ice accumulation and breakage (Urie, 1971).

It appears that in both the Seabrook and Gerber systems the tree cover disappeared mainly because of management practices, such as poor matching of the water distribution systems to the structural characteristics of the trees.

In the Seabrook and Gerber forest systems the tree cover was destroyed partly because water distribution systems were not adjusted to structural characteristics of the trees.

3) The most intensive study to date is that begun at Pennsylvania State University in 1963. Treated municipal sewage effluent has been spray-irrigated in forested areas on two different soils for over 10 years. The sites include two mixed-hardwood stands (mainly oak), a red pine plantation, and a young plantation of white spruce in an old field that initally supported a variety of native grasses also. Application rates ranged from 1-4 in./week over the growing season and in some cases extended the year around. Many detailed results are available in publications (Parizek et al., 1967; Sopper and Kardos, 1972; Murphy et al., 1973; Wood et al., 1973; Sopper and Kardos, 1973; Sopper, 1975; Richenderfer et al., 1975; Kardos and Hook, 1976).

Wastewater renovation by the forest vegetation itself is generally acceptable, but not nearly as efficient as by agronomic crops (Table 7). Nevertheless, tree growth was generally stimulated by irrigation (Table 8). The major exception was red pine irrigated with 2 in./week. This species is subject to root damage on wet soils and after five years of irrigation, a wind storm following wet snow felled every tree on the plot.

Additional results indicate that effluent irrigation somewhat enhanced wood fiber quality of red pine and red oak as raw material for pulp and paper (Murphy et al., 1973). In contrast, irrigation with 1 to 2 in./week of wastewater had a detrimental

TABLE 7. Renovation efficiencies[1] for treated municipal sewage effluent applied to corn and hardwood forest, Pennsylvania State University

Nutrient	Corn Silage	Hardwood Forest
N	145%	39%
P	143%	19%

[1]% of element applied which is removed by vegetation itself. Application rate 2 in./week. Additional phosphorus fixed by soil. Source: Sopper, 1975.

TABLE 8. With one exception, wastewater irrigation materially increased tree growth in the Pennsylvania State University studies.

	Ave. Annual Diameter Growth - mm		Ave. Annual Height Growth - cm	
Species and Rate	Control	Irrigated	Control	Irrigated
White Spruce				
2 in./week	4.5	10.0	13	46
Red Pine				
*1 in./week	1.5	4.3	42	58
*2 in./week	1.8	1.5	52	49
Mixed Hardwoods				
*1 in./week	4.1	4.6		
**2 in./week	3.3	5.6		
***4 in./week	3.8	5.3		

* growing season only
** year around
***various schedules

Source: Sopper, 1975

effect on the mechanical properties of red pine crown wood (Murphy and Brisbin, 1970). Effluent irrigation has also reduced the number of tree seedlings and increased mortality of older saplings in hardwood stands at Penn State. After one year of irrigation, seedling numbers were 16- and 14 thousand per acre on the control and irrigated hardwood plots, respectively. Ten years later the comparable numbers were 14 and 2 thousand, respectively. During the same period, mortality of saplings and large trees was about 20% higher in irrigated areas. The decrease in seedling numbers may have resulted from less light at the forest floor because of stimulated overstory growth. Increased mortality of older trees was largely due to ice damage during periods of winter irrigation. Ice damage must be expected if application systems operate during winter months, although it can be minimized with proper design of sprinkler systems (Myers 1973).

Wastewater irrigation increased tree growth in most species in a Penn State study.

Tree seedling and cutting irrigation shows promise

Recent studies conducted at the University of Washington (Breuer, Cole and Schiess, 1977) show good results in terms of nitrogen leaching to groundwater, and other wastewater renovation goals, for Douglas fir seedling and poplar cutting plots compared to a predominately reed canary grass plot. These three test areas, along with a bare soil plot, were established in 1974 on land which had previously been clear-cut of Douglas fir.

Application of secondary treatment plant effluent was made to all plots at 5 cm (2 in.) per week year-round during 1975 and 1976, and percolate was sampled at various depths via lysimeters. Mean annual applied NH_4^+ concentration was 16.5 mg/l and total N concentra-

tion was about 18.5 mg/l. All of the vegetated plots produced groundwater quality well within the 10 mg/l standard for nitrate concentration, at six-foot depths.

The Douglas fir plot also included a lush growth of native grasses and herbs, which had to be cut several times during 1975 and 1976, and may have contributed to the overall nutrient removal efficiency of this plot. The poplar plot also included native grasses which were also well established during 1975. However, much improved growth of the tree cuttings in 1976 resulted in greatly reduced growth of the grass, and nitrogen uptake efficiency as shown by the percolate studies was dramatically improved.

This work may have positive implications for the technique of wastewater application to fast-growing tree species, then harvesting in relatively short rotations. Longer term data from this and similar studies would be very useful, as well as more specific studies to determine plant uptakes versus soil mechanisms, particularly for nitrogen.

Options exist in managing forest systems

Overall objectives will play a major role in the way forest land is employed in the design and operation of waste application systems. Three basic options are:

(1) Maximize waste application and accept the resulting site changes in vegetation. Essentially this approach amounts to letting the natural vegetation adapt to a new regime of high soil moisture, high fertility, and mechanical damage.

(2) Maximize renovation by adapting waste application to existing soil and vegetation. Increased growth yields may constitute an added benefit.

(3) Manage so as to maximize quantity and/or quality of timber, pulpwood, or other product. In this approach, highly in-

tensive forest management techniques
are required.

Obviously, intermediate alternatives exist but these three options delineate the general range of choices.

Park and Recreational Applications

Treatment sites can be used for recreation

Recreation includes dozens of activities in which people commonly engage for relaxation. There are water sports - fishing, boating, swimming, diving, etc., and land sports - tennis, cycling, walking, golf and so on. Water sports are commonly split into two categories pertinent to the present discussion: contact and non-contact sports. For example, a non-contact sport is boating; contact sports are swimming and diving. The water quality required for non-contact sports is lower than for contact sports. The water quality standards for recreational uses of water normally are published by each state, and should be referred to by those planning to incorporate water-based recreation in the land application system.

Water quality standards for recreational use of reclaimed wastewater are set by each state.

Parks, golf courses use effluent for irrigation

Land-based recreational sites can utilize wastewaters for irrigation and fertilization. Golf courses, university campuses, city parks, and so on have successfully been developed and maintained using effluent waters and sludges. Providing irrigation for golf courses and landscape areas such as campuses and highway median strips is a costly practice in the arid areas of the country. The use of treated wastewater for such irrigation has been practiced for several years in many of these states. Wastewater for landscape irrigation is normally a secondarily-treated and disinfected effluent. Wastewater irrigation of these areas serves a dual purpose: it saves the municipality the cost of irrigating with potable water, and provides additional treatment for the wastewater before discharge into surface or ground

Using reclaimed wastewater for irrigating golf courses, campuses, and other landscaped areas is especially attractive in arid areas.

waters.

Perhaps the most well-known park developed using effluent is the Golden Gate Park in San Francisco. The rich soil of the park was developed on sand dunes using the street sweepings of decades ago, when horses provided the main energy for transportation. The park was originally irrigated by an outfall sewer traversing the park, but with development of the area came complaints of objectionable odors, and the practice was discontinued. The purchase of potable water was too expensive. An activated sludge sewage treatment plant was completed in 1932 and supplied 1 mgd treated effluent for irrigation of the 1,013 acre park.

Several golf courses have been established as well as maintained using effluent from secondary treatment plants. Table 9 lists some of the communities which irrigate golf courses with municipal effluent and the date when their land application projects were begun (EPA, 1973). Many of the designs of recent projects have taken advantage of earlier experience and their own test plots. Experience at the Ventura, California golf course (Sullivan, 1970) resulted in the following recommendations:

(1) Hardy species indigenous to the area should be planted whenever possible for landscaping, golf course hazards, etc. Keeping the ground moist for the first 2-3 weeks after seeding maintains low soluble salt concentrations and insures quicker ground cover and thicker stands.

(2) Adequate disinfection is necessary to protect the public health. California considers adequate disinfection to be achieved when

TABLE 9. Location of golf courses irrigated with municipal effluent (and date land application was started)

Arizona	
City of Prescott	(1960 - 62)
City of Lake Havasu	(1971)
California	
City of Ontario, San Bernadino County	(1915)
Santee County Water District, San Diego County	(1959)
City of San Clemente	(1957 - 68)
City of San Bernadino	(1962)
City of Laguna Hills	(1964)
City of Livermore	(1965)
City of Ventura	(1965)
Colorado	
City of Colorado Springs	(1953)
New Jersey	
City of Cranbury	(1967)
New Mexico	
City of Santa Fe	(1962)
Texas	
City of Abilene	(1920)
City of La Mesa	(1960)

Source: EPA, 1973

the number of coliforms does not exceed a MPN of 23/100 mℓ. Careful monitoring of daily flow and chlorine residual should be practiced.

(3) Pipelines should be designed without cross connections between potable and effluent supplies. Valves and sprinkler heads should be tagged and colored so as to warn the public. Special protection should be provided for drinking fountains on the golf course.

(4) A wastewater application rate of 60 inches/acre/year was appropriate at Ventura.

Folowing a pilot study, the decision to irrigate the golf course with effluent was made. The program was later expanded to include water hazards on the golf course and a recreational lake. A public information program run concurrently with the pilot study was effective and there was no problem of acceptance by the public by the time the project was completed.

Suhr (1971) has reviewed case studies of treatment works which discharge effluent to potable water supplies. Experience has shown that it is possible for land treatment to meet water quality standards for swimming and other contact sports. If not overloaded, land treatment can even result in effluent of drinking water quality. In fact most communities rely upon such natural purification to maintain the quality of their groundwater supplies. This does not mean, however, that it is easy to renovate water to the point that it may be used for a recreational lake.

Wastewater may be renovated by land treatment to a quality high enough for swimming.

Each state establishes water quality standards which include designation of certain waters within the state for specific purposes. The classification of the water would then determine the quality of effluent which may be discharged into the various waterways.

Designers of land application systems who plan to utilize the wastewater for recreational activities which involve the water itself, be they contact or non-contact activities, should be aware of local and state regulations, and be prepared to meet the standards for water quality at the recreational impoundment. It is beyond the scope of this program to provide the participants with water quality standards for all the states; these standards can be requested from state health departments or pollution control agencies.

Each state sets standards for purity of recreational waters.

California has promulgated specific water quality standards for reclaimed wastewater for various uses in the reference Wastewater Reclamation Criteria (1975). Article 6 refers specifically to recreational impoundments. For non-contact sports such as fishing, boating, etc., the reclaimed wastewater shall be "adequately disinfected (and) filtered". It "shall be considered adequately disinfected if at some point in the treatment process the median Most Probable

Number (MPN) of coliform organisms does not exceed 2.2/100 mℓ. The median value shall be determined from the bacteriological results of the last 7 days for which analyses have been completed." For contact sports (swimming, wading) the wastewater must be adequately disinfected and oxidized. Disinfection will be deemed adequate on the same basis as for non-contact water. For a landscape impoundment, that is, one which is used only for aesthetic enjoyment and with which the public has no contact, the wastewater must be adequately disinfected and oxidized. MPN of coliform organisms in non-contact waters should not exceed 23/100 mℓ (Foster, 1969).

Several land application systems are being managed so as to produce recreational water areas. Not surprisingly, it is the arid western and southwestern regions of our nation where techniques to reclaim and reuse wastewater have been most fully explored. The water hazards at the Ventura golf course and the lakes at Lancaster, California north of Los Angeles are examples of non-contact recreational areas.

Lancaster recreational lakes illustrate nutrient problems

Dryden and Stern (1968) provided an extensive review of the waste quality criteria which were adapted by them in the planning of the recreational lakes at Lancaster, California. A waste flow of 3 MGD received primary treatment followed by biological stabilization in oxidation ponds. The most severe limitation encountered in attempts to renovate the oxidation pond water to a point where it was suitable for use in the lakes was the removal of phosphorus to a concentration of 0.5 mg/ℓ or less. At dissolved phosphorus concentrations higher than 0.5 mg/ℓ algae growth was so fast that fish could not survive. During the day the algae used up all CO_2 dissolved in the water resulting in a pH rise to between 8.5 and 9.5 which may have been toxic to fish as a result of ammonia toxicity.

During the nights, respiration of large algae and bacterial populations reduced dissolved O_2 of the water to as low as 1 mg/ℓ, which is too low for fish. At 0.5 mg/ℓ algae growth continued but at a reduced rate and few extreme conditions were encountered. Still, in order to assure population stability it was considered necessary that some method of supplementing the oxygen content of recreation lake water should be provided for emergency use.

Land treatment sites can be wildlife habitats

Increased interest in the conservation of our natural resources has led to a greater awareness of how our lifestyle affects the other life forms which share our environment. With the expansion of our population, we are in fact crowding out many plants and animals, and many are even being driven to extinction. Happily, the land application alternative to waste management in most cases does not reduce wildlife habitat; indeed, it may even serve to provide new habitat in areas that have been devoid of wildlife for decades. Little work has been done on managing land application sites for wildlife habitat. However, work at the Pennsylvania State University has shown that chlorinated effluent sprayed on wildlife areas has little or no effect on the wildlife occupying these areas. Some results of these studies will be reviewed in this module.

A study shows application of chlorinated effluent in wildlife areas has little or no effect on wildlife.

Many land application system operators have noted an influx of wildlife, particularly waterfowl (duck, geese, grebes, and so on), when water is allowed to accumulate in ponds or marshy areas. Leicester, New York is the site of a food processing plant where wastewater is sprayed onto forested areas, and tends to pond in low areas and ditches. These wet spots harbor several broods of black ducks and mallards.

It must be remembered that standing water in wastewater irrigation areas may lead to increased mosquito populations and other nuisances. This can be of overriding concern, and must be carefully evaluated against the practice of allowing water to stand stagnant in these areas.

The members of a community may be interested in creating or expanding wildlife habitat for several reasons. An important ecological concept is that diversity of populations is crucial to ecosystem stability. A greater number of different species of plants and animals (diversity) will lead to a more stable natural community than a community with only a few different plant and animal species. In agricultural areas, natural scrub or woodland interspersed with large fields may encourage small birds and mammals to remain in an area. This may have a moderating influence on insect pest problems.

Incorporating a wildlife habitat into the land application scheme may make land treatment more acceptable to the community.

Hedgerows have been used, traditionally, as fences to separate small fields. Increasingly, hedgerows have been removed form agricultural fields because they may harbor insect pests and provide alternate hosts for diseases, because they increase the number of turns required in working fields, and because they accumulate snow in northern winters which can delay field operations in the spring. Hedgerows may make a contribution to land application sites in that they often make a site more attractive to visitors, because they help to control water and wind erosion and because they are effective in blocking aerosol drift from spray irrigation. Areas which are too steep or too close to a stream for field operation should also not receive wastewater irrigation but may yet provide a wildlife habitat (Figure 4). With proper management, an effluent-irrigated area could thus provide a very important and useful adjunct to the community which it serves.

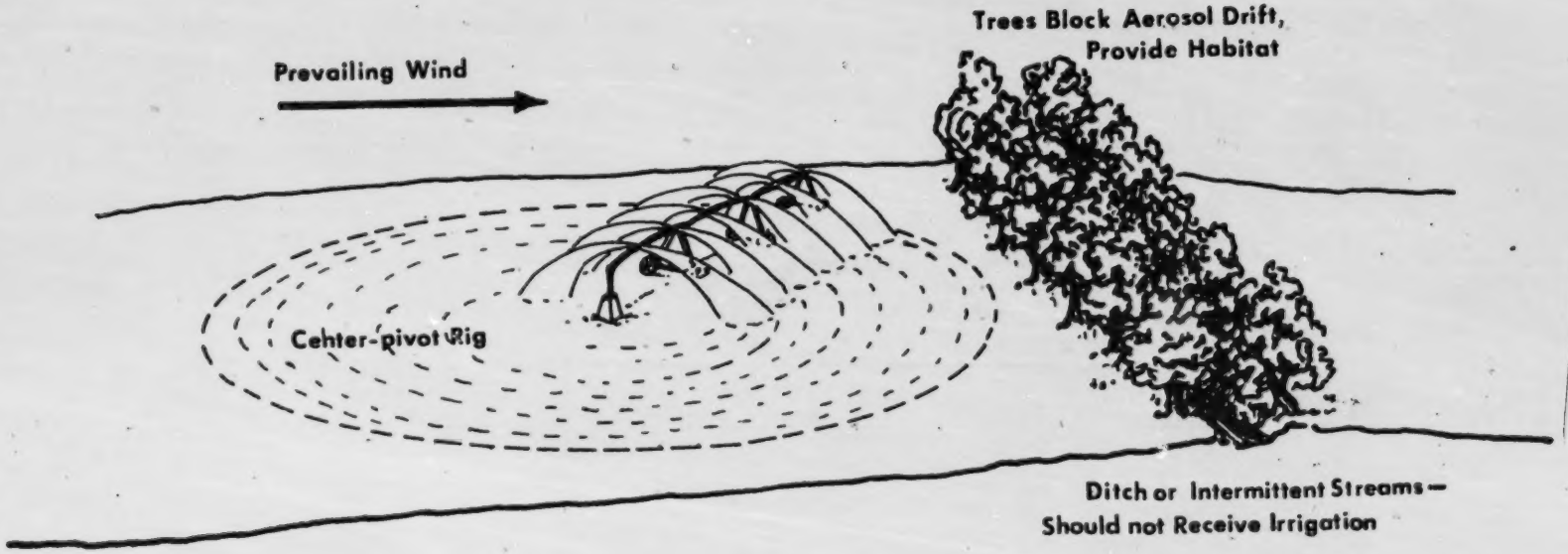


FIGURE 4. Hedgerow vegetation may be planted along spray fields to aid in aerosol control and provide habitat for small mammals and birds.

Management of land application systems for wildlife habitat must of course take into account the design criteria developed for protection of the public health and the environment. In most cases, wildlife attraction will be a secondary benefit of a forested site or a site with marshy areas. An example of a marsh system which is suffessfully polishing secondary effluent while providing a diversified habitat for many wetland species is the Mt. View Sanitary District operation at Martinez, California. System operators may wish to capitalize on this aspect, and build up a large enough wildlife population to allow limited hunting. This may be especially practical for waterfowl. A fair sized marsh, properly managed for wastewater application and planted with the proper vegetation, should quickly lure waterfowl, which in turn will lure hunters, if the manager of the site so desires. This kind of facility may in fact attract additional support from a community for the land application alternative. It should be remembered that hunting is an emotional issue and the wants and needs of the community must be addressed if such a possibility is to be contemplated. The same groups within a community which oppose hunting will probably support a wildlife preserve wholeheartedly. The person responsible for designing the site and negotiating with the community should keep in mind this sort of emotional response to an issue. A full discussion of community interaction in land treatment planning is included in Module 1, "Societal and Legal Constraints".

As mentioned previously, the only extensive research reported as of 1977 on effects of land application systems on wildlife has been conducted by Penn State. For detailed information, the participant is referred to the work of Wood, Glantz and Kardel (1975).

The study included several investigations of responses of small mammals and deer to the conditions prevailing at a land application site. Studies included uptake and the concentration of heavy metals, incidence of disease, changes in populations, changes in feeding habits and other activities. The Abstract, Conclusions and Recommendations of the study group appear in Appendix A.

The study at Penn State showed that, in general, wildlife was not adversely affected by spray irrigation of wastewater. The only significant difference was an increase in the body weight of young rabbits in the fall. It must be remembered, however, that other geographical areas will represent different situations, and that changes occur gradually. In the early years of irrigation at Seabrook, New Jersey, it was also concluded that the increased herbage growth provided a better habitat, more shelter and food, for small mammals (Mather, 1953).

Just as a soil scientist should be engaged to appraise the soil at a site, so should a wildlife biologist be consulted to evaluate the stability of a desirable wildlife habitat. Such professional help will allow the system designer to maximize the benefit to be gained from such management. Questions to be kept in mind for such consultation will include which species should be managed, what vegetation will attract these species while remaining amenable to the wastewater irrigation situation, and so on. To be sure, creating a lake in the desert will have a greater effect on neighboring wildlife than would creation of a marsh in the northeast, where marshes are relatively abundant.

The land treatment operator should consult a wildlife biologist to evaluate the site as a possible wildlife habitat.

Recommendations exist for recreation areas using wastewater

The recommendations listed below should be kept in mind when designing a land application site which will be managed to derive a secondary benefit of

recreation or wildlife habitat. They are non-specific in nature. Specific guidelines for individual sites must be generated with the site in mind. As discussed earlier, public health regulations in which each state sets water quality for water sports must be consulted. For wildlife habitat expansion, a wildlife biologist should be retained. He or she can provide valuable information as to how to manage a site for wildlife in general, or for particular species of interest.

Recommendations for land activities: Recreation areas which utilize effluent irrigation must have controlled access. The public should not be allowed into the area when spraying is being conducted. The site must be laid out so that when certain areas are being sprayed, these areas will not be available for use. Adequate warning signs should be erected to keep the public away from areas during irrigation. The site must have sufficient time to rest between applications of wastewater and entrance by the public.

- Plant species should be chosen both for their suitability to the recreation area and for their tolerance to effluent irrigation. The high nutrient content of the effluent will encourage luxuriant growth. This must be kept in mind when determining mowing schedules and other daily operating procedures.

- Loading rates must not exceed the infiltration capacity of the soil. The ultimate fate of applied water should be determined.

Recommendations for water activities:

- Individual state public health regulations must be obeyed for contact and non-contact water sports.

- If a body of standing wastewater is incorporated into the recreation area, such as a water hazard at a golf course, warning signs should be erected to warn against drinking of the water by the public.

- Constant monitoring and record-keeping are necessary where wastewater is reclaimed and used for swimming. The facility should be able to close down immediately on detecting a health hazard in its water.

Recommendations for wildlife habitat:

- Any standing water, such as marshes and ponds, should be posted against drinking and body contact to protect the public health.

- Any effluent containing pesticides or other chemicals which are known or suspected of being harmful to wildlife must not be disposed of on wildlife areas.

- Wildlife populations should be monitored. Dramatic increases in populations should be counteracted by harvesting (hunting or trapping). Disease outbreaks must also be monitored, as wildlife disease organisms may not be detected in normal public health monitoring.

- If public use of the wildlife areas is encouraged, the recommendations listed above for land activities must also be considered.

Land Reclamation and Revegetation

Wastewater can be used for reclaiming mined areas

Thousands of acres in this country have been disturbed to get at the valuable coal and mineral deposits which lie beneath the surface. In the past, little thought has been given to reclaiming the barren wastelands which are the result of these mining operations. However, all states now mandate - and environmental concern reiterates - that newly mined areas must be restored to an acceptable condition by those responsible for mining them. Surface mining of coal, gravel, sand, iron ore, phosphates and kaoline clay is the most common method of retrieving these materials from the earth. Underground mining of coal also results in surface degradation. The low grade coal that is not economical to process, and the rock associated with the coal, is all brought to the surface. This spoil is heaped into mountains, where it mars the landscape, and causes runoff problems after rains.

Surface and underground mining in the U.S. have degraded large areas of land; federal law is increasingly requiring that this land be reclaimed.

While today most states have laws requiring some degree of restoration of strip mined land, a U.S. Department of the Interior report (1967) indicated that 66% of the 3.2 million acres which had been disturbed was considered unreclaimed. This represents an area approximately equal in size to the state of Delaware. It was considered that 20% of these existing spoils would be difficult to vegetate with traditional methods due to their physical or chemical characteristics.

Reclamation is an expensive and difficult process. A promising method of reclamation utilizes sludge and wastewater to restore precious nutrients to the land so that vegetation can be supported. Other waste materials which are being evaluated as amendments to mine spoil include composted garbage and fly ash

The addition of sludge and wastewater to mine spoil and mined areas can restore nutrients to the land so vegetation can grow.

(Bennett et al., 1976). Utilization of these materials in conjunction with each other may prove to be cost effective treatment although environmental questions have not been fully answered.

Surface mine and spoil material lack organic matter

Land that has been surface mined, or strip-mined, has had many or all of the soil layers removed, intermixed with each other, and dumped in piles. As we know from Module 3, "Soil as a Treatment Medium", the soil is a delicate system which must be kept intact in order for it to properly carry on its processes. Spoil material may be considered to be soil parent material rather than soil. Nearly all essential minerals are found to some extent in this material. Organic matter, however, is virtually nonexistent. Table 10, taken from Czapowskyj (1973), lists the major nutrient contents of some coal mine spoils.

Because mine spoil is devoid of organic matter, has low water holding capacity and little aggregate stability, it cannot support vegetation.

In terms of texture, two thirds of surface spoil material is finer than sandy loam, one third is coarser. On coarse piles, in spite of steep slopes, surface runoff is essentially never observed. Subsurface leachates may nevertheless cause serious water pollution problems, and surface creep may result in the continued exposure of fresh spoil material (Harrison, 1974). Vegetation establishment on coarse material is particularly hampered by a lack of water. Even the finer spoil materials tend to have a low available water holding capacity. The finer material has practically no aggregate stability and tends to form crusts which deter vegetative establishment (Bennett et al., 1976). The finer material is subject to surface runoff, and even light suspended solids loads can be quite damaging. Harrison (1974) explains, "Coal and coal shales have a density of less than 2.0 g/cm^3, and often approach 1.0 g/cm^3. Therefore, the maximum particle size that will stay in suspen-

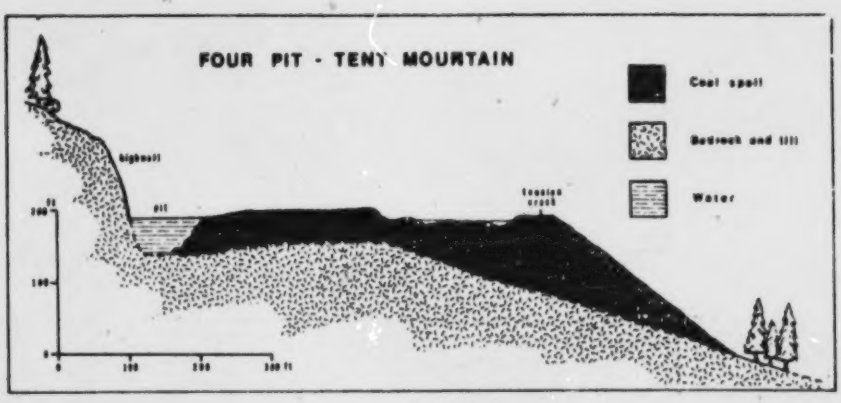
TABLE 10. Main nutrient contents of some coal-mine spoils

Spoil	pH	N	P	K	Ca	Mg
		pct.	ppm		mg/100 gm.	
KENTUCKY--BITUMINOUS						
Shale--black	2.2	--	--	<0.1	1.0	2.3
Shale--gray	5.0	--	--	0.8	5.5	4.8
Shale--gray	6.2	--	--	0.6	8.6	4.2
INDIANA--BITUMINOUS						
Sandstone	4.0	<0.1	16.6	<0.1	1.8	0.6
Shale--gray	4.7	<0.2	6.6	<0.1	3.5	1.5
Glacial till	7.3	<0.1	15.6	0.1	17.5	3.5
PENNSYLVANIA--ANTHRACITE						
Breaker refuse	2.9	<0.1	10.7	0.4	3.2	0.3
Sandstone	6.3	0.1	41.9	0.2	2.9	0.3
Glacial till	7.1	<0.1	64.2	0.2	2.4	0.4

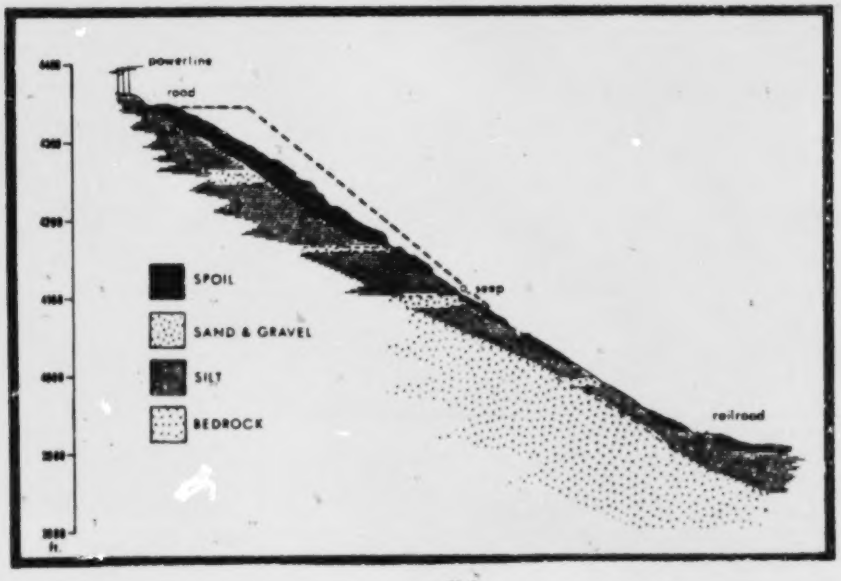
Source: Czapowskyj (1973)

sion under given conditions is much larger than for other materials...a small amount of suspended coal dust in a stream or lake has a much greater effect on water color and the transmission of light than an equal weight of other mineral matter."

In mountainous regions, spoils are often dumped in a fashion similar to that depicted in Figure 5. Numerous measurements of dump piles have established that 37° is the average angle of repose of spoil (Harrison, 1974). Major slides of this material can occur if material underlying the toe of a dump pile fails. Seepage waters may increase the likelihood of such failures (Figure 5(b)). If no provision is made for drainage of abandoned pits (Figure 5(a)), accumulated water will raise the water table within the spoil and contribute to failure as a result of the increased weight of the spoil mass, reduction of the effective intergranular pressure due to the buoyancy



(a)



(b)

FIGURE 5. Cross sections through waste dumps: (a) cross section from headwall to natural hillside. Four Pit, Tent Mountain, Alberta; (b) cross section from dump to railway, Erickson Pit, Michael, B.C.

Source: Harrison (1974)

effect, and seepage pressure (Harrison, 1974).

Spoil banks often present a chemical environment hostile to life. While some spoil banks may be readily revegetated, others remain unvegetated for many years. The pH of these "orphan lands" is usually very low. This acidity is an important factor in mobilizing toxic elements, particularly Al, Fe, and Mn, thus preventing revegetation. Experience in Alberta, Canada indicates that most cultivated crops, and especially legumes such as alfalfa, encounter toxicity problems with levels of aluminum greater than 2.0 ppm and levels of manganese greater than 15.0 ppm (Taylor and Gill, 1974).

Spoil banks often present a chemical environment hostile to life.

Iron pyrite brought to the surface as part of the mine spoil is responsible for much of the acidity at very acid sites. Exposed to the atmosphere, iron pyrite is readily oxidized to ferrous sulfate and sulfuric acid (Hill, 1971) according to the following reaction:

$$2FeS_2 + 2H_2O + 7O_2 \rightarrow 2FeSO_4 + 2H_2SO_4$$

Because of the instability of steep spoil piles, new pyrites are continually brought to surface, thus maintaining the acidity of some spoil banks.

Reclamation efforts aimed at revegetation

The most important decision which must be made prior to beginning a reclamation project is the final use of the site once it has been reclaimed. The great majority of reclaimed mine areas in humid regions of this country have been planted to forest. Some of these forests are managed for fiber production, while others are allowed to develop in natural succession. Other management schemes for reclaimed areas have included airstrips, housing developments, parklands, industrial parks, and so forth. Many of these uses could be compatible with continued wastewater application and site monitoring. In almost all types of potential land use considered, establishment of vegetation is essential. This is most difficult on very

Before reclamation is begun, the final use of the site must be determined.

acid and very steep spoils in very dry areas.

Before reclamation of spoil bank material is attempted, the bank may need to be leveled, graded and perhaps contoured. Whereas the angle of respose of spoil material averages 37°, the "biological angle of respose" appears to be between 25° - 30° (Harrison, 1974). On steeper slopes the rate of growth of a plant's root system is not rapid enough to allow it to anchor itself against the slow downhill movement of the soil cover (surface creep). Shrubs tend to dam material on their uphill side, while material below moves away, exposing roots. Trees are bent and fall over before reaching sufficient size to resist this movement.

While spoil banks naturally lie at about a 37° angle, a 25° - 30° slope is much better for establishing vegetation.

Even on sites graded to 25° it may not be easy to establish vegetation. Aids to vegetative establishment which have been effectively used include mulches, nurse crops, lime, fertilizer, seed bed preparation, seed mixture, timeliness and method of sowing, and seeding rate. The following observations have been made. Mulches and nurse crops aid establishment by reducing surface creep, increasing moisture at the soil surface, reducing temperature and protecting seedlings from wind driven abrasive material (Bennet et al., 1976). Lime helps to neutralize the acidity of the site and reduces the availability of toxic elements. Rock phosphate has been used effectively because it contains 40% CaO equivalents as well as phosphorus. Rock phosphate is normally reacted with sulfuric acid to form superphosphate fertilizer. The same neutralizing reaction occurs when it is added to very acid mine spoils (Bennett et al., 1976). Nitrogen and phosphorus are the main elements deficient on coal mine spoils. Potassium may also be needed on kaoline spoils. The supply of micronutrient Mn, Zn, Ca and S range from toxic levels in extremely acid spoils to adequate in moderately acid spoils (Czapowskyj, 1973).

Many additives and management techniques can be employed to promote spoil bank revegetation.

Excessively smooth surface grading of fine textured spoils can lead to sheet erosion and poor seedling establishment. A preferred procedure is to leave furrows running across the slope to catch and hold seed and fertilizer (Bennett et al., 1976). Hydroseeding, using water as a carrier of seed and fertilizer, will result in a more uniform distribution of seed where cyclone seeding is hampered by high winds or steep slopes (Bennett et al., 1976). Most studies have concluded that only species which are likely to dominate should be seeded, that these should be sown at rates sufficient to provide good cover, and that the best planting time is just before the wettest season of the year (based on probability) (Schuman et al., 1976).

The selection of adapted species has received considerable investigation. Recent reviews of some of this information were presented by Schuman et al. (1976) for the western U.S. and by Bennett et al. (1976) for the eastern regions. The latter review contains information on some little-known legumes which may prove useful.

In recent years, some mining operations have attempted to remove the surface soil layers carefully, pushing them into separate piles, so that they can be replaced on top of the spoil pile once one has been removed from the site. This is a costly but effective method of assuring that revegetating plant roots may contact organic matter. As discussed in Module 3, "Soil as a Treatment Medium", organic matter is beneficial in a number of ways: it holds water, forms complexes with toxic elements, and it provides a steady balanced supply of nitrogen, phosphorus and potassium.

Sludge and wastewater alter spoil banks

Municipal wastes tend to have a pH of about 6.8 - 7.2. In addition to their value as a source of water, they are high in the dissolved minerals, nutrients

and organic matter that plants need, and that are lacking in the spoil bank material. Characteristics of these wastes are more fully discussed in Module 5, "Waste Characteristics".

Municipal wastes have structural and chemical characteristics that spoil bank material lacks.

Case studies on reclamation field work

Penn State Studies: In 1968, a study was undertaken at Pennsylvania State University to determine if municipal sewage sludge and wastewater could be used to aid in the revegetation of spoil bank material (Sopper, Dickerson, Hunt & Kardos, 1970). It was hypothesized that the slightly alkaline sludge would help to neutralize the highly acid spoil material, and that the nutrient-rich wastewater would leach acids and toxic elements to below plant root depth, as well as provide organic colloids, which would detoxify the soluble iron, aluminum and manganese. Table 11 lists the average composition of effluents and sludges used in some experiments at Penn State.

Initial experiments consisted of establishing ten test plots, each containing about 25 tons of highly acid (pH 2.0 - 3.0) spoil material from the lower Kittanniny bituminous coal seam in Clearfield County, Pennsylvania. This material was chosen because several attempts at revegetating it had failed over the past 23 years. The plots were boxed in plywood lysimeters each 32 feet long, 4 feet wide, and 4 feet deep, open on the bottom, and located in an open field. Six inches of sand were placed in the bottom of the boxes to facilitate monitoring of the percolate.

In the spring of 1969, liquid sludge and wastewater were applied to the boxes. The wastewater was applied at the rate of 0.5 inches per hour by a rotating sprinkler. Liquid sludge was applied from a tank truck. Seven species of trees were randomly planted in the boxes, including Japanese larch, white spruce, Norway spruce, white pine, European alder, hybrid poplar, and black locust. In addition, two grass species, K-31 tall fescue and orchard grass, and two legumes, crown vetch

TABLE 11. Average chemical composition of sewage effluent and liquid digested sludge (from Sopper and Kardos, 1972).

Constituent	Sewage Effluent		Digested Sludge	
	1969	1970	1969	1970
	mg/ℓ		mg/ℓ	
Nitrate - N	6.1	11.8	---	---
Kjeldahl N	34.4	6.2	932	1,430.0
NH_4	11.9	2.9	---	---
Phosphorus	5.24[1]	5.55[1]	111.0[2]	118.0[2]
Potassium	13.7	22.4	79.6	48.5
Calcium	34.9	29.5	136.5	58.8
Magnesium	16.0	15.1	33.8	19.0
Sodium	35.2	31.7	33.8	30.3
Manganese	0.04	0.10	1.30	0.98
Boron	0.36	0.20	0.40	0.59
Chloride	43.2	37.3	---	---
Sulfate	--	38.6	---	---
Aluminum	0.9	1.3	57.5	30.5
Iron	0.5	0.6	14.8	8.5
Zinc	0.11	0.22	1.8	1.7
Copper	0.17	0.1	1.4	1.2
pH	7.2	6.9	7.6	7.5
Dry solids (%)	---	---	3.2	3.8

[1] Soluble orthophosphate

[2] Total phosphorus

and birdsfoot trefoil, were planted.

Several application rates were used to determine the best application regimen. The control boxes were not irrigated at all after planting. Other treatments included 1) 1 inch of effluent plus one inch of sludge per week, 2) 2 inches of effluent per week, 3) 2 inches of sludge per week, and 4) 2 inches of effluent plus 2 inches of sludge per week. Treatment continued for 24 weeks.

One study showed application of both sludge and wastewater to spoil material enhanced seed germination and vegetative growth.

Vegetative growth in several plots was impressive. The best treatments for germination and growth included application of both sludge and effluent. The wastewater irrigation washed the sludge solids from the plants, which prevented the foliage damage experienced by the plants receiving only sludge application. Black locust was the most successful tree in terms of survival percentage and height growth. The only treatment which affected a significant change in the pH of percolate collected at a depth of 3.5 feet was the two inches effluent and sludge per week treatment. Under this regimen, the pH went from 2.2 - 2.8 to 4.1 (Sopper et al., 1970). This treatment had the best height growth for tree seedlings and the greatest dry matter production of grasses and legumes. This treatment also resulted in the highest values for phosphorus and nitrate-nitrogen, and lower for manganese, iron and aluminum in the percolate. Reductions in K, Ca, Mg, Zn, B, and Cu concentrations in the percolate were also noted in the irrigated boxes as compared to the control boxes. According to Sopper and Kardos (1972) "irrigation with effluent and sludge leached and diluted the native salts, and solubilities of the Mn, Fe, Al, Cu, and Zn were suppressed by the dual action of alkalinity of the effluent and sludge and humic precipitation by the organic colloids of the sludge."

The results of a subsequent study initiated in 1971 (Edgerton, et al., 1975) utilizing similar applications to 8 grass and 8 legume species are presented in Table 12.

Table 12. Dry matter production and height growth of grasses and legumes for the two treatments. No grass or legume germination occurred on the controls.

Species	1-Inch Combination Treatment DMP (pounds per acre)	1-Inch Combination Treatment Height (feet)	2-Inch Combination Treatment DMP (pounds per acre)	2-Inch Combination Treatment Height (feet)
Grass				
Weeping Lovegrass	6127	1.45	11067	1.35
Blackwell Switchgrass	2702	1.60	4689	2.80
Deertongue	2212	0.50	4624	0.65
Reed Canarygrass	636	0.75	3215	1.25
Redtop	259	0.45	1845	0.55
Garrison Creeping Foxtail	0	—	1284	0.50
Climax Timothy	83	0.55	1112	1.60
Saratoga Smoothbrome	52	0.40	929	0.65
Legume				
Ladino Clover	214	0.50	3078	0.70
Iroquois Alfalfa	405	0.65	3060	1.10
Sericea Lespedeza	501	0.75	2887	1.05
Pennscott Red Clover	519	1.10	2717	1.15
Bristly Black Locust	1193	1.15	2431	1.95
Sweet Clover	0	—	1424	1.15
Chemung Crownvetch	51	0.30	907	0.50
Lathro Flatpea	123	0.40	761	0.55

Source: Ebgerton, B. R., W. E. Sopper, and L. T. Kardos, 1975.

The small-scale lysimeter studies at Penn State are ongoing, but they have already demonstrated that with proper site preparation and application of sludge and wastewater, very acid strip mine spoil bank material may be revegetated. Revegetation is the crucial first step in reclaiming land, for without vegetation, there can be no stabilization of the piles of spoil material. Eventually, this reclaimed land can be put to a useful purpose, whether as a forest, recreation area, housing, or other kind of development. As was discussed earlier in this module, the decision as to how a site will be managed will lie in the hands of the community in which the site is located.

Scranton tests show good results with sludge application

Scranton, PA: Once the study group at Penn State found that strip mine spoil material could be revegetated in a laboratory situation, they decided to start a small scale revegetation project. The Scranton, Pennsylvania area was the scene of much mining activity in the past. Deep-mining for coal has left mountains of spoil material throughout the area and runoff from them turns the Lackawanna River bright yellow.

The city of Scranton and its neighboring boroughs are built around and on piles of waste from the old mining operations. An economical method of reclaiming these sites and putting them to beneficial use would certainly be welcome.

In 1974, three plots were laid out at the Cedar Avenue Mine Bank by the Penn State workers. The first received 15 inches of effluent on a 60 foot by 60 foot area over a two month period. Sludge was applied to subplots at the rate of 0, 20, 40, and 80 tons per acre. A second plot was treated with the same amount of sludge but fresh city water. A third plot received only

sludge and natural precipitation. A fourth control plot received no sludge and no irrigation of any sort. Nine inch tree seedlings were planted along with grass and legume seeds.

Although there was no treatment during the second season, all the planted vegetation did well on the treated plots. The greatest success has been on the plots which received only dried sludge. The sludge was applied and mixed into the spoil material by hand. No odor or other deleterious effect was noted in the area. This field study of reclaiming spoil banks is hopefully the first of many attempts to revegetate such waste areas and make them productive - or at least pleasant to look at.

Scranton study showed dried sludge application to be most effective in promoting growth of tree seedlings on strip mine spoil material.

Palzo study shows need for high rates of sludge application

The Palzo Tract, Illinois: A tract in the Shawnee National Forest in Illinois was established in 1970 as a demonstration site to evaluate sludge application on strip-mined land (Lejcher and Kunkle, 1973). Anaerobically digested sludge from the Metropolitan Sanitary District of Greater Chicago (MSDGC) was used. Within the 77 hectare site, known as the Palzo Tract, 4 plots 500 square meters each were delineated. Water quality and plant response were measured continually.

The plots were treated with 304, 178, 78, and 0 dry metric tons of sludge per hectare. The next spring, the plots were seeded with K-31 tall fescue and weeping lovegrass at rates of 22 and 8 kg/hectare.

Germination occurred within 30 days on all but the control plot. At the end of the first growing season the most heavily treated plot showed 90% vegetative cover. Plots with lower treatment rates had less than 50% cover. Similarly, only the plot with the highest application rate was able to support the same amount of coverthe second year as it did the first.

The Palzo Tract studies indicated that sludge application on strip mine spoil must be at a level

high enough to neutralize the acidity of the spoil to allow establishment of vegetation. Table 13 presents data on pH changes on sludge-amended spoil material. Table 15 reports the concentrations of selected elements in percolating waters.

Palzo Tract studies show that sludge application on strip mine spoil must be high enough to neutralize the acidity of the spoil.

Conclusions from field studies suggest possibilities for further work

It is evident from these results as well as from those obtained at Penn State that despite contributions of large amounts of toxic and trace elements, waste additions can actually decrease the amount of some of these elements in the soil solution. All elements, however, do not behave in the same way. In the Penn State study, waste application decreased concentrations of Al, Fe, Mn, and Ca. In Illinois, however, Zn as well as Cd and Cr were increased. These results suggested that a serious problem of heavy metal leaching may be encountered if the alkalinity of wastewaters alone is relied upon to neutralize acid mine spoils. Note that Cd and Cr levels measured in the percolate from both treated and controlled plots exceed by a considerable amount the levels specified in the National Interim Primary Drinking Water Regulations (EPA, 1976).

Treatment of mine spoils with the residues from coal-fired power plants (fly ash, bottom ash, and flue gas desulfurization (FGD) sludge) may be another example of additions of potentially toxic elements which may result in reduced overall availability of those elements. Power plant wastes are generally very alkaline and often have good water retention characteristics. Concern has been expressed over high Se and Mo concentrations in forage crops grown on mine spoils heavily amended (100-600 tons/acre) with fly ash. Boron toxicity to plants is also a likely problem. As discussed in other modules, however, boron will leach fairly quickly from a site, and Mo and Se toxicities are associated primarily with crops grown on alkaline soils. Moderate fly ash additions to acid mine spoils might result in a much more neutral, much less toxic substrate for plant growth than

either substance taken alone. Total additions of toxic elements would be much less than if wastewaters were used to give a comparable degree of neutralization. Wastewater additions to a neutralized spoil-ash

TABLE 13. Effect of sludge treatment on pH of spoil within the plots at the Palzo Tract, Illinois (from Lejcher and Kunkle, 1973).

Treatment Rate (dry metric tons/hectare)	Plot Average Soil Surface pH
304	6.2
178	5.2
78	4.7
0	2.3

TABLE 14. Average concentration of certain parameters in subsurface runoff from the sludge treated plots at Palzo before and after treatment ("after" values based on 1970-1972 averages) (Lejcher and Kunkle, 1973).

	Treatment (metric tons/hectare)						
	-304-		-178-		-78-		-0-
	Before	After	Before	After	Before	After	Average
Element	-milligrams per liter-						
Al	1,240	402	395	138	440	346	548
Cd	1.14	1.92	0.31	1.18	0.70	1.13	0.66
Cr	3.5	4.8	1.3	1.6	2.3	3.4	2.1
Cu	11.6	7.5	3.8	3.3	4.0	3.6	4.5
Fe	3,700	1,260	1,280	320	1,000	822	1,620
Mn	70	30	51	17	71	42	36
Pb	0.33	0.23	0.16	0.18	0.42	0.18	0.22
SO_4	11,000	7,740	8,400	3,730	7,100	6,770	7,980
Zn	24.4	36.4	8.1	24.8	14.1	26.0	13.3
Acidity	22,940	8,900	7,310	3,320	7,040	5,900	9,770

mixture should result in a medium with improved water retention characteristics, and the additions of N, P, K, and organic matter should favor plant growth. Bern (1976) has argued that in the near future "economic forces will dictate a combined coal refuse/power plant residuals operation." Such operations would be facilitated by locating power generating plants close to coal deposits, so called "mine-mouth power stations". Applications of wastewaters to such carefully monitored sites may well prove a cost effective treatment in active mining areas.

Wastewater additions to power plant residues would probably improve water retention, add nutrients and build organic matter.

Studies show corn reacted much more successfully in sludge-amended than untreated mine spoils

Agricultural use of reclaimed strip mine land: In Illinois, anaerobically digested liquid sludge has been applied to strip mine land. The land was subsequently planted to corn. Attempts at growing corn on unamended strip mine land have had poor results. Average yields for this situation was 13 bushels per acre, and the corn was of poor quality. A study was conducted to determine the physical-chemical characteristics of corn grown on amended strip mine land, as well as the heavy metal content of the crop (Garcia et al., 1974).

Commerical yellow seed corn was used for the study. One plot of strip-mine land was treated with sludge equivalent to a loading of 25 tons of solids per acre. An adjacent plot received no sludge addition. Of particular interest to the workers was the question of whether heavy metals (Zn, Mn, Cu, Pb, Cr, Cd, and Hg) were translocated in the plant, especially to the edible parts.

A physical examination of the corn from the two plots showed a dramatic difference in success. The corn from the untreated plot looked immature, and reflected stress conditions. Kernel size was small to intermediate, and about 20% of the kernels were

diseased. Corn kernels from the treated plots showed only minor variation in size, and there were no diseased kernels in the sample. The corn appeared similar to commercial grade corn. The weight of the corn grown on the sludge-amended plots was about four times greater than the weight of corn grown on the untreated plot. The weight of the cob, and the number of kernels per cob, was about three times greater for corn grown on the treated plot.

Chemical analyses similarly revealed greater success for corn grown on the sludge-amended sites. Protein, fat, and fiber values were lower for corn from the untreated sites. The increased protein content showed that the sludge amendment definitely improved the nutritional quality of the corn.

The heavy metal analysis did not reveal any significant difference in heavy metal content between corn from treated and untreated plots in this short term study. The only exception to this was zinc, which was higher in the untreated corn. The concentration of zinc in the cobs and husks from untreated plots was about three times higher than that from treated plots. The workers hypothesized that this high concentration of zinc was due to the organically-deficient strip mine spoil on which the corn was grown.

While increased levels of toxic elements were not found in corn in this study, the concentration of cadmium in the soil (spoil) material was increased from less than 2 ppm to over 70 (Garcia et al., 1974). Other studies (see module 20, "Crop Selection") have shown that corn is a poor test crop because it particularly excludes Cd and that such elevated levels of soil cadmium may represent a hazard. It would seem that there is no reason to expect mine spoil to accept larger quantities of toxic elements than would prime agricultural soils, while still remaining productive. Indeed, to the extent that they may become acid if not properly managed, they may be deemed less ap-

Mine spoil cannot be expected to accept larger quantities of toxic elements from sludge than prime agricultural soils; in fact, they will more likely accept less if not properly managed.

propriate receptors.

In certain situations, strip mined soils may be reclaimed to the point where they may be used to produce healthful crops. Managed in this fashion, they would be subject to the same constraints discussed in Module 20, "Crop Selection." No agricultural soil will remain productive if it is too heavily contaminated with industrial wastes.

BIBLIOGRAPHY

Akin, E. W., W. H. Benton, and W. F. Hill. 1971. Enteric viruses in ground and surface water: a review of their occurrence and survival. In Virus and water quality: occurrence and control. 13th Water Quality Conference, 59, Univ. of Illinois. 222 p.

Ballard, R. and J. G. A. Fiskell. 1973. Phosphorus retention in coastal plain forest soils. Soil. Sci. Soc. Amer. Proc. 38: 363-366.

Bastian and Whittington. 1977. Current EPA guidance on land application of municipal sewage sludges. pp. 13-14. In Disposal of residues on land. Proceedings of the National Conf. on Disposal of Residues on Land, Sept. 13-15, 1976, St. Louis, MO. Information Transfer, Inc. Rockville, MD, 216 p.

Bennett, O. L., W. H. Armiger, and J. N. Jones, Jr. 1976. Revegetation and use of eastern surface mine spoils. pp. 195-215. In Land application of waste materials, Soil Conservation Society of America, Ankeny, Iowa. 313 p.

Bern, J. 1976. Residues from power generation: process, recycling and disposal. pp. 226-248. In Land application of waste materials. Soil Conservation of America, Ankeny, Iowa. 313 p.

Bormann, F. H., G. E. Likens, and J. M. Melillo. 1977. Nitrogen budget for an aggrading northern hardwood forest ecosystem. Science, Vol. 196, pp. 981-983.

Boyle, J. R. 1975. Nutrients in relation to intensive culture of forest crops. Iowa State J. Res. 49: 297-303.

Bryan, F. L. 1974. Diseases transmitted by foods contaminated by wastewater. Presented at the Conference on the Use of Wastewater in the Production of Food and Fiber. Oklahoma City, Oklahoma.

Breuer, D. W., D. W. Cole, and P. Schiess. 1977. Nitrogen transformation and leaching associated with wastewater irrigation in Douglas-fir, poplar, grass, and unvegetated systems. (Unpublished paper). College of Forest Resources, Univ. of Washington, Seattle. 33 p.

Czapowskyj, M. M. 1973. Establishing forest on surface-mined land as related to fertility and fertilization. Forest Fertilization Symposium Proc., USDA Forest Service General Technical Report NE-93, pp. 132-139.

Dryden, F. D., and G. Stern. 1968. Renovated wastewater creates recreational lake. Environ. Sci. Technol. 2(4): 268-278.

Edgerton, B. R., W. E. Sopper, and L. T. Kardos. 1975. Revegetating bituminous strip-mine spoils with municipal wastewater. Compost Science 16(4): 20-25.

EPA. 1976. National interim primary drinking water regulations. EPA-570/9-76-003. 159 p.

EPA. 1975. Technical bulletin. Evaluation of land application systems. 430/9-75-001.

EPA. 1974. Land application of sewage effluents and sludges: selected abstracts (abs #015M and 020M, 2841). 660/2-74-042.

EPA. 1973. Survey of facilities using land application of wastewaters. 430/9-73-006.

Fisk, W. W. 1964. Food processing and waste disposal. Water and Sewage Works. 111: 417-420.

Foster, H. B., Jr., and W. F. Jopling. 1969. Rationale of standards for use of reclaimed water. J. San. Eng. Div., Proc. A.S.C.E., SA (3): 503-514.

Garcia, W. J., C. W. Belssin, G. E. Inglett, and R. O. Carlson. 1974. Physical-chemical characteristics and heavy metal content of corn grown on sludge-amended strip-mine spoil. J. Agr. Food Chem. 22(5): 810-815.

Harrison, J. E. 1974. Geologic aspects of mountain coal mine waste disposal. In Land for waste management, proceedings of the international conference at Ottawa, Canada, October 1973, the Agricultural Institute of Canada, Ottawa. 388 p.

Henderson, G. S., and W. F. Harris. 1975. An ecosystem approach to characterization of the nitrogen cycle in a deciduous forest watershed. pp.189-193. In Bernier, B. and C. H. Winget, ed. Forest soils and forest land management. Laval Univ. Press, Quebec. 676 p.

Herrick, A. M., and C. L. Brown. 1967. A new concept in cellulose production: silage sycamore. Agr. Sci. Rev. Fourth Quarter, pp. 8-13.

Hill, R. D. 1971. Restoration of the terrestrial environment. The ASB Bulletin 16(3): 107-116.

Hook, J. E., and L. T. Kardos. 1977. Nitrate relationships in the Penn State living filter system. pp. 181-198. In R. C. Loehr, ed. Land as a waste management alternative. Proceedings of the 1976 Cornell Agricultural Waste Management Conference, Ann Arbor Science Pub., Inc. Ann Arbor, Michigan. 811 p.

Jorgensen, J. R., C. G. Wells, and L. J. Metz. 1975. The nutrient cycle: key to continuous forest production. J. Forest. 53: 400-403.

Kardos, L. T. and J. E. Hook. 1976. Phosphorus balance in sewage effluent treated soils. J. Environ. Qual. 5: 87-90.

Lance, J. C. 1972. Nitrogen removal by soil mechanisms. J. Water Pollution Control Fed. 44: 1352-1361.

Lejcher, R. and S. R. Kunkel. 1973. Restoration of acid spoil banks with treated sewage sludge. pp. 184-186. In W.E. Sopper and L. T. Kardos, eds. Recycling treated municipal wastewater and sludge through forest and cropland. Penn. State Univ. Press, University Park, Pa. 479 p.

Little, S., H. W. Lull, and I. Remson. 1959. Changes in woodland vegetation and soils after spraying large amounts of wastewater. Forest Sci. 5: 18-27.

Mather, J. R. 1953. The disposal of industrial effluent by woods irrigation. Trans. Amer. Geophys. Union. 34: 227-239.

Merrell, J. C., Jr., and P. C. Ward. 1968. Virus control at the Santee, Calif. project. Amer. Water Works Assn. J. 60: 145-153.

Munro, J. K., Jr., R. S. Luxmore, C. L. Begovich, K. R. Dixon, A. P. Watson, M. R. Patterson, and D. R. Jackson. 1977. Transport model to predict the movement of Pb, Cd, Zn, Cu, and S through a forested shed. pp. 45-38 In Disposal of residues on land. Information Transfer, Inc. Rockville, Maryland. 216 p.

Murphey, W. K., R. L. Brisbin, W. J. Young, and B. E. Cutter. 1973. Anatomical and physical properties of red oak and red pine irrigated with municipal wastewater. pp. 295-310. In Sopper, W. E., and L. T. Kardos, eds. Recycling treated municipal wastewater and sludge through forest and cropland. The Penn. State Univ. Press. Univ. Park, Pa. 479 p.

Murphey, W. K., and R. L. Brisbin. 1970. Influence of sewage plant effluent irrigation on crown wood and stem wood of red pine. Pa. Agr. Exp. Sta., Univ. Park, Pa, Bull. 772. 29 p.

Myers, E. A. 1973. Sprinkler irrigation systems: design and operation criteria. p. 324-333. In Sopper, W. E. and L. T. Kardos, eds. Recycling treated municipal wastewater and sludge through forest and cropland. The Penn. State Univ. Press. Univ. Park, Pa. 479 p.

Nutter, W. L. and R. C. Schultz. 1975. Spray irrigation of sewage effluent on a steep forest slope, I. Nitrate renovation. Agron. Abst. Amer. Soc. Agron. Madison, WI.

Parizek, R. R., L. T. Kardos, W. E. Sopper, E. A. Myers, D. E. Davis, M. A. Farrell, and J. B. Nesbitt. 1967. Wastewater renovation and conservation. Penn. State Univ. Studies No. 23. Univ. Park, PA. 71 p.

Peterson, M. et al. 1973. A guide to planning and designing effluent irrigation disposal systems in Missouri. U. of Mo. Extension Division. NP 337 3/73/1250. 90 p.

Plass, William T. 1974. Factors affecting the establishment of direct-seeded pine on surface-mine spoils. USDA Forest Services Res. Paper NE-290.

Powers, R. F., K. Isik and P. J. Zinke. 1975. Adding phosphorus to forest soils: storage capacity and possible risks. Bull. Environ. Contam. Toxicol. 14: 257-264.

Richenderfer, J. L., W. E. Sopper, and L. T. Kardos. 1975. Spray-irrigation of treated municipal sewage effluent and its effect on chemical properties of forest soils. Gen. Tech. Rep. NE-17. USDA, Forest Service, NE Forest Exp. Sta. Upper Darby, PA 24 p.

Rudolph, V. J. 1957. Further observation on irrigating trees with cannery waste water. Mich. Agr. Exp. Sta. Quarterly Bull. 39: 416-423.

Rudolph, V. J. and R. E. Dils. 1955. Irrigating trees with cannery waste water. Mich. Agr. Exp. Sta. Quarterly Bull. 37: 407-411.

Schultz, R. C., W. L. Nutter and G. H. Brister. 1975. Spray irrigation of sewage effluent on a steep forest slope, II. Vegetation, forest floor, and soil variations. Agron. Abst. Amer. Soc. Agron. Madison, WI.

Schuman, G. E., W. A. Berg and J. F. Power. 1976. Management of mine wastes in the western United States. pp. 180-194 In Land application of waste materials. Soil Conservation Society of America. Ankeny, IA. 313 p.

Sopper, W. E. 1975. Wastewater recycling on forest lands. pp. 227-243. In Bernier, B. and C. H. Winget, eds. Forest soils and forest land management. Laval Univ. Press, Quebec. 675 p.

Sopper, W. E. and L. T. Kardos. 1973. Vegetation responses to irrigation with treated municipal wastewater. pp. 271-294. In Sopper, W. E. and L. T. Kardos, eds. Recycling treated municipal wastewater and sludge through forest and cropland. The Penn. State Univ. Press. Univ. Park, PA 479 p.

Sopper, W. E. and L. T. Kardos. 1972. Effects of municipal wastewater disposal on the forest ecosystem. J. Forestry 70: 540-545.

Sopper, W. E. and L. T. Kardos. 1972. Municipal wastewater aids revegetation of strip-mined spoil banks. J. Forest 70(10).

Sopper, W. E. et al. 1970. Revegetation of strip-mine spoil banks through irrigation with municipal sewage effluent and sludge. Compost Science, Nov.-Dec. pp. 6-11.

Stevens, L. A. 1974. Clean water. E. P. Dutton, N.Y. 289 p.

Stevens, R. M. 1972. Green land-clean streams. Center for the Study of Federalism, Temple Univ. Philadelphia, PA. 330 p.

Suhr, L. G. 1971. Some notes on reuse. Journal AWWA. Vol. 63, pp. 630-634.

Sullivan, D. L. 1970. Wastewater for golf course irrigation. Water and Sewage Works 117(5): 153-159.

Sutherland, J. C., J. H. Cooley, D. G. Neary, and D. H. Urie. 1974. Irrigation of trees and crops with sewage stabilization pond effluent in southern Michigan. pp. 295-313 In Wastewater use in the production of food and fiber. EPA-660/2-74-041. Proceedings of the conference held in Oklahoma City, OK March 5-7.

Switzer, G. L., L. E. Nelson and W. H. Smith. 1972. Nutrient accumulation and cycling in loblolly pine (Pinus taeda L.) plantation ecosystems: the first twenty years. Soil Sci. Soc. Amer. Proc. 36: 143-147.

Switzer, G. L., L. E. Nelson and W. H. Smith. 1968. The mineral cycle in forest stands. pp. 1-9. In Forest fertilization. TVA, Muscle Shoals, AL.

Tamm, C. O., H. Holmen, P. Popovic and G. Wiklander. 1974. Leaching of plant nutrients from soils as a consequence of forestry operations. Ambio. 3: 211-221.

Taylor, K. G. and D. Gill. 1974. Environmental alteration and natural revegetation at a mine site in the Northwest Territories, Canada. pp.16-25. In Land for waste management, proceedings of the international conference at Ottawa, Canada - October, 1973. The Agricultural Institute of Canada, Ottawa. 388 p.

Trimble, G. R., Jr., R. S. Sartz and R. S. Pierce. 1958. How types of soil frost affect infiltration. J. Soil Water Conserv. 13: 81-82.

Urie, D. H. 1971. Opportunities and plans for sewage renovation on forest and wildlands in Michigan. Mich. Acad. 4: 115-124.

Urie, D. H. 1975. Nutrient and water control in intensive silviculture on sewage renovation areas. Iowa State J. Res. 49: 313-317.

U.S. Department of the Interior. 1967. Surface mining and our environment. U.S. Dept. of the Interior. 1967-0-278-800. 124 p.

Van't Woudt, B. and R. M. Hagan. 1957. Crop responses at excessively high soil moisture levels. In Drainage of agricultural lands. American Society of Agronomy, Madison, Wis. 620 p.

Webster, B. 1975. Bullrushes being used in artificial marshes to filter water. N.Y. Times, 9 March.

Wood, G. W., P. J. Glantz, D. C. Kradel, and H. Rothenbacher. 1975. Faunal response to spray irrigation of chlorinated sewage effluent. Institute for research on land and water resources. Publication No. 87, The Penn. State Univ. Press. University Park, PA. 89 p.

Wood, G. W., D. W. Simpson, and R. L. Dressler. 1973. Effects of spray irrigation of forests with chlorinated sewage effluents on deer and rabbits. In Sopper, W. E. and Kardos, L. T., eds. Recycling treated municipal wastewater and sludge through forest and cropland. The Penn. State Univ. Press. University Park, PA. pp. 311-323.

Woodwell, G. M., J. Ballard, J. Clinton, M. Small, and E. V. Peron. 1974. An experiment in the eutrafication of terrestrial ecosystems with sewage. Evidence of nitrification in a late successional forest. pp. 215-228 In Sutherland et al. (cited above).

Younger, V. B., W. D. Kesner, A. R. Berg, and L. R. Green. 1973. Ecology and physiological implications of greenbelt irrigation with reclaimed wastewater. pp. 396-407 In W. E. Sopper and L. T. Kardos, eds. Recycling treated municipal wastewater and sludge through forest and cropland. The Penn. State Univ. Press, University Park, PA. 479 p.

APPENDIX

Effects of spray irrigation of treated wastewater on wildlife (Wood, et al., 1975)

ABSTRACT

The only significant difference found in a 3-year comparison of cottontail rabbit *(Sylvilagus floridanus)* populations confined to non-irrigated and sewage effluent irrigated aspen-white pine-shrub habitat was in the significantly heavier body weights in the fall of juveniles on irrigated sites.

Comparison of spring and fall populations of mice *(Peromyscus* spp.*)* in non-irrigated, effluent irrigated, and sludge-injected effluent irrigated mixed-oak forest habitat revealed no population density differences between irrigated and non-irrigated sites during spring. Fall 1973 populations were significantly different with higher densities on irrigated sites, and these densities were greater on sludge-injected effluent sites than effluent only sites.

Analyses of liver, kidney and bone tissues for cadmium, chromium, copper, nickel, lead and zinc were done on cottontail rabbits from effluent irrigated and non-irrigated sites. Copper was the only element found to be significantly higher ($P > 0.05$) in concentration in rabbits from irrigated sites and this only in kidney tissue. Unexplainably rabbits from irrigated sites showed significantly ($P > 0.05$) lower concentrations of cadmium in liver; cadmium, nickel, and lead in kidney; and copper in bone tissue.

Whole-body analyses of dry ashed white-footed mice carcasses for chromium, nickel, lead and zinc were also made. Ten animals were taken from each of the following: effluent irrigated site, sludge-injected effluent site, and a non-irrigated control. Chromium levels were higher and nickel levels were significantly lower ($P > 0.05$) on the effluent irrigated site. Otherwise there were no statistically significant differences.

Studies of the effects of effluent irrigation on production, nutritive quality, and use of deer forages in mixed-oak forest stands showed no significant differences in site feeding capacity between irrigated and non-irrigated sites in late spring. Summer production of palatable forage on the non-irrigated site far exceeded that of the irrigated site. Paradoxically, use of irrigated sites by semi-free ranging white-tailed deer *(Odocoileus virginianus)* exceeded use of the non-irrigated sites in both spring and summer.

Studies of songbirds revealed that their use of irrigated areas declined during the time of irrigation. In aspen-white pine-shrub habitat, activity on irrigated sites was higher than non-irrigated sites on non-irrigation days. This was due primarily to the increased amounts of brush caused by greater winter ice damage to sapling trees on irrigated sites which created a more favorable habitat for certain species of birds. Activity on non-irrigated mixed-oak forest stands was greater than that on similar irrigated stands during the early summer. The reverse was true, in late summer when surface soil macro-organisms that served as a food source were apparently more available on the irrigated sites.

Preliminary investigations of mosquito populations in the irrigation area and at similar remotely located control areas suggested that population densities were greater in the general area of irrigation. There were no demonstrable differences between irrigated sites and sites close to them that were not irrigated. *Aedes vexans* and *Aedes trivittatus* were by far the dominant species present, except at 1 site located about 8 km from the irrigation facility, where species of the genus *Culex* were dominant.

A very limited investigation of the possible influence of wastewater irrigation on disease incidence in several species of wild mammals revealed no evidence of leptospirosis in specimens taken from irrigated or non-irrigated sites. Coccidiosis was common in populations of cottontail rabbits confined to non-irrigated and irrigated sites, and its occurrence was greater among juveniles on irrigated sites. Sereological tests of blood from deer, opossum, cottontail rabbits, humans, and domestic rabbits serving as sentinel animals for California encephalitis, St. Louis encephalitis, and Powassan, revealed only antibodies for California encephalitis in some individuals of all species, but there was no evidence of a difference in incidence of disease that might be caused by wastewater irrigation.

Microbiological examination of the wastewater for total coliform, fecal coliform and fecal streptococci showed that 100 percent of the sludge-injected effluent samples had counts exceeding 1000 per 100 ml for each of these forms. Only 26 percent of the effluent samples had counts of this magnitude. Studies of fecal samples from rabbits, deer and songbirds revealed 16 *E. coli* O-groups in animals from irrigated areas. These O-groups were not found in animals from non-irrigated areas. Eleven of the above mentioned O-groups were found in the wastewater itself. There were 6 *Klebsiella sp.* isolates found in the wastewater and 46 found in the wild birds and mammals. There was no conclusive evidence of increased frequency of this organism due to irrigation, however. *Salmonella sp.* was not found in wastewater samples, although it was isolated from 1 songbird fecal sample.

CONCLUSIONS

The conclusions drawn from these studies of limited intensity should not be considered definitive for 3 reasons. First, the time span of this research is short relative to that during which a wastewater system may create environmental changes in a particular ecosystem. Second, the communities of plants and animals that were available for study were limited to those on sites already being irrigated, which was mostly a mixed-oak forest stand of large pole to small sawtimber, and an early successional community of an aspen-white pine-shrub complex. Third, due to the limited size of study sites and the time span of the study, relatively small numbers of animals have been observed, which seriously limits the researchers' ability to extrapolate the findings to large populations over large areas. Within these limits the findings suggest:

1. Three years of irrigation for aspen-white pine-shrub communities with chlorinated sewage effluent did not result in any net losses in cottontail rabbit reproduction.

2. The changes in the cottontail rabbit habitat in the aspen-white pine-shrub communities appeared to be the result of 3 factors:

   a. General increase of concentrations of crude protein, phosphorus, potassium and magnesium occurred, but concentrations of calcium dropped in both summer and winter forages.

   b. The extensive ice damage to saplings and shrubs caused by winter irrigation increased the amounts of available forage, both winter and summer.

   c. The ice formations on shrubs and trees surrounding irrigation sprinklers increased the amount of winter cover.

3. Irrigation of cottontail rabbit habitat apparently had little influence on body weights of adult animals in the fall. It did appear to result in increased weight in juvenile animals, however.

4. The amounts of deer forage available on irrigated and non-irrigated mixed-oak forest sites in late spring were not meaningfully different. Summer irrigation, however, tended to enhance greatly the production of unpalatable herbaceous species and effectively lowered the feeding capacity considerably below that of the non-irrigated site. Yet, the preference factors for 5 out of 6 palatable species which grew on both sites were higher on the irrigated site.

5. Irrigation may raise the concentrations of crude protein, phosphorus, potassium, and magnesium; lower the concentration of calcium; and have no effect on crude fiber or *in vitro* dry matter digestibility of deer forage.

6. Chlorinated effluent does not deter the use of irrigated sites by deer. In fact, deer may use these sites more often than non-irrigated sites, possibly due to the greater amounts of vegetative cover on the former.

7. Irrigation apparently has no effect on spring populations of mice *Peromyscus*. Fall populations, however, may be higher on irrigated than non-irrigated sites due to increased density of herbaceous vegetation associated with effluent irrigated and sludge-injected effluent sites.

8. Songbird use for an area appears to be primarily related to the type of habitat that is being irrigated and the time of irrigation. In sapling tree stands that are heavily damaged by ice and consequently produce more brush, one may expect greater songbird use by species such as song sparrows, yellowthroats and gray catbirds. The effect of irrigation on mixed-oak tree stands for songbird use may depend on 2 things. First, winter irrigation may result in the loss of understory saplings and low tree branches due to ice damage. They would otherwise be used for perching and nesting sites during the summer. When food is equally abundant on irrigated and non-irrigated sites, those with perching facilities will be preferred. Second, when seasonal changes in moisture stress result in greater surface soil macro-organism activity, greater songbird use may be expected of the irrigated sites. Songbirds will avoid irrigated areas during the time of irrigation.

9. Irrigation of forested areas will probably enhance the production of mosquitoes, particularly those of the genus *Aedes*. The interaction of the increased mosquito populations and increased songbird activity may provide an important interface for arbovirus transmission.

10. There is no conclusive evidence to indicate an increased incidence of diseases in wild animals as a result of irrigating an ecosystem with municipal wastewater. In systems of neutral to alkaline soil conditions, the changed moisture regime could be favorable for the survival of leptospires, but, so far, if this is happening it apparently has not manifested itself epidemiologically. California encephalitis in the mosquito and wild mammal populations can be expected in wastewater irrigated ecosystems in Pennsylvania. There is no evidence, however, to show that its frequency of occurrence is any greater or less than in similar non-irrigated ecosystems.

11. Bacterial agents (*E. coli*, possibly *Klebsiella* sp. and others) will survive sewage treatment and are introduced into irrigated ecosystems. This consequently affects the bacterial populations of ponds in the area. However, more conclusive data are needed to verify transmission of these micro-organisms from wastewater to wild animals, and their beneficial or detrimental effect to the health of the host.

12. If concentrations of cadmium, chromium, copper, nickel, lead and zinc are increasing in the bodies of small herbivorous mammals feeding on irrigated sites, the changes are either quite small or not detectable by the sampling techniques. This does not mean that concern for this aspect of the study should be minimized, but suggests that some long term monitoring should be used, should these contaminants become saturated in irrigated soils.

RECOMMENDATIONS

The results are not definitive as to what the response of wild animals will be to the practice of irrigating municipal wastewater on forest and farm land. They do point out areas that need continuing research.

First, the effects of wastewater irrigation on the occurrence of biting insects is in great need of intensive investigation. Changes in population size and species composition of these insects may be reflected in the potential for disease transmission in the irrigated area. In addition, insect populations will influence the comfort of both people and animals who use the area.

Second, changes in the occurrence of potentially pathogenic organisms that might result from wastewater irrigation should have further research and should be part of a constant system of monitoring. The greatest limitation to conclusions from short-term, single-attempt studies is that no basis for comparison of present and previous figures is available. This work has provided some information, but no data existed with which it could be compared. A plan should be devised to provide for systematic sampling in the irrigated area and in a control area, which would not only serve as a public health measure but also provide long-term research data.

Approximately 10 years of research has convinced many people that sewage effluent can be disposed of safely by irrigation. Relative to the thoroughness with which effluent spray irrigation has been researched, little evaluation of sludge-injected effluent has been done. Because of its high bacterial counts and heavy metal concentrations any recommendation to a municipality of this procedure for sludge disposal should be carefully considered in perspective with the other alternatives. In addition it should then only be recommended as an experimental procedure with contingency plans to alleviate adverse environmental effects should they arise.

Third, The Pennsylvania State University Wastewater Renovation Facility is a prototype that is serving as a model. An important area of information that has not come from this facility, but which could be developed, would provide guidelines for choosing wastewater renovation sites, preparing environmental impact statements for the facilities, and environmental parameter monitoring. The lack of data on such aspects as faunal response is partly to blame, but most of the problem is due to the difficulty of assembling an interdisciplinary group of scientists to study the problems and report their findings.

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NON-CROP AND FOREST SYSTEMS

Objectives

Upon completion of this module, the participant should be able to:

1. Describe the characteristics of forest land which favor and disfavor it as a land treatment site.

2. List the different options for managing forest land used for a waste application site.

3. Describe how wastewater can be used to create and enhance recreation sites.

4. Summarize the case of Santee, California, in its efforts to use reclaimed wastewater for swimming.

5. Describe the chemical and physical characteristics of mine spoil material and how it can be amended with the addition of sludge and/or wastewater.

6. Describe one study which experimented with adding sludge and/or wastewater to former mining areas, specifying the results of such additions.

RETURN TO
LESSON PACKAGE

Script to Accompany the A-T

NON-CROP AND FOREST SYSTEMS

Module 13

January, 1978

NON-CROP AND FOREST SYSTEMS

(Slide 1) This A-T focuses on alternative sites for wastewater application besides the most popular site agricultural land (Slide 2). Forest lands (Slide 3), abandoned mining areas (Slide 4), urban green belts, and recreation areas can be considered as sites.

The objectives for this module are located in the envelope labelled objectives that came with the A-T package. Stop the tape and study the objectives (Slide 5). You may keep the objectives for reference during the module.

We will first examine the use of forest land as a waste treatment site.

In the Eastern and Northeastern United States, forests are abundant near urban areas (Slide 6). Research indicates that waste application to trees can contribute to renewing the wood fiber resources and solve waste recycling problems. Such systems can be successful if proper tree species are selected; waste applications are properly adjusted to the ecological requirements of the trees; distribution systems are designed to fit structural characteristics of forests; and the optimum tree production systems are selected, installed and properly managed (Slide 7). Very few municipalities or industries, however, have used this alternate management scheme, and studies on the efficacy of forest land as a waste treatment site are sparse. Slide 8 shows that fewer than a dozen projects nationwide focused on evaluating forests for waste recycling in 1974.

What are the advantages of using forest land? It is abundant. Forestland comprises 33% of the total land area of the contiguous United States (Slide 9). Forest land is less expensive to buy than agricultural land. Forest products are not directly consumed by humans, thus avoiding any public health problems. Direct contact of humans with waste treated forest land is less likely, reducing the possibility of adverse public reaction to the waste treatment. Forests are often abundant near urban areas where wastes are generated. Forest land sites are also suited to small towns where urban sprawl is minimal and where the treatment plant may be located in or nearby a wooded area (Slide 10).

Because of the vastness of forest land acreages, new areas could be treated successively by using portable piping (Slide 11). Towards this eventuality, specie tolerances and standloading rates must be researched to assure landowners that no harm will come to their forest land, that wastewater will be adequately renovated, and that benefits may accrue.

Forest soil generally has much higher infiltration and percolation rates than agricultural soil.

Forests are better able to accept waste application in winter (Slide 12). Due to the insulating properties of the forest floor, soil frost may not even form. If the forest floor does freeze, it is usually of the "honeycomb" type, which maintains high porosity (Slide 13). Irrigation of the forest can improve understory vegetation and thereby increase food and cover for birds, rabbits, and deer (Slide 14).

Although there are many positive attributes of using forest land as a waste treatment site, the use of naturally occurring forest land does present problems (Slide 15). Some forests often occupy adverse sites such as shallow soils, imperfectly drained soils, and steep rocky hillsides (Slide 16). Forests frequently occur on sands (Slide 17), which are not as favorable for mineral retention as are soils with substantial colloidal content. However, the abundance of forest land makes consideration of low rates of effluent application over large areas of land possible.

The conclusions of research to date indicate that generally forest land has a limited nutrient uptake unless intensive cropping techniques are used (Slide 18). There have been notable exceptions to the data reported in this slide, however, which are discussed later.

In natural stands of forests, vegetation has adapted to relatively infertile soil conditions by efficient recycling of nutrients. Unless intensive cropping techniques are used then, only a small percentage of nutrients are ever removed from the forest even though the annual uptake of nutrients by the forest flora compares with certain agronomic crops. Instead, the nutrient rich leaves, twigs, bark and roots are returned to the soil as shown in Slide 19, until decomposition renders them available for plant uptake. At any given time, the majority of nutrients are tied up in the forest floor or in the soil organic matter. This slide shows the distribution and annual cycling of nitrogen in an oak-hickory

forest in Tennessee. Notice that most of the nitrogen is tied up in the mineral soil, with lesser amounts in the forest floor and the vegetation.

The capacity of natural forest stands to renovate wastes depends largely on the successional stage of the forest as shown in Slide 20. During early development when the stand is building nutrient-rich tissues, such as a canopy of tree crowns and meristems, nutrient accumulation will be highest. In contrast, near mature or climax forests accumulate lesser quantities of nutrients.

As Slide 21 indicates, forestland can be very efficient at retaining phosphorus. The data are from the first two years of an ongoing study at the University of Washington. The renovation efficiency for phosphorus is greater than 99% in this study. Total phosphorus retention is strongly related to soil depth. Deeper soils are capable of binding more phosphorus, all other factors being equal. Highly weathered sands, however, with low iron and aluminum levels may retain no appreciable phosphorus.

The fate of nitrogen in forest sites is not as certain. However, fresh carbon provided by annual litter fall and root turnover, together with periodic anaerobic conditions caused by heavy wastewater additions, makes denitrification look promising as a nitrogen renovating mechanism. As shown in Slide 22 and in Module 15 "Nitrogen Considerations", denitrification requires the presence of both nitrate and decomposable organic substances under anaerobic conditions. Nitrate is seldom abundant in forest soils. The primary control in nitrate production may simply be the supply of ammonium ions. In unamended forest soils, the small amounts of available ammonium contributed by precipitation inputs or mineralization of organic nitrogen are quickly utilized by plant roots and microorganisms. This makes the populations of nitrifying bacteria low. But an influx of ammonium from wastewater additions would probably result in population changes and lead to increased nitrification after a period of adjustment.

In Michigan, red pine on sandy soil was irrigated with municipal effluent at rates of up to 8.8 centimeters per week (Slide 23). In early evaluations, needle length and dry weight increased up to 36 and 56% respectively, when compared to the control. Renovation efficiency was 83% or better at 60 centimeters depth with nitrate nitrogen not exceeding 1 part per million.

A study at the University of Washington, mentioned earlier, is proving to be very interesting in indicating the possibilities of wastewater renovation using forest land. Initially four plots were used for wastewater application. The plots were recently clear cut Douglas Fir forest. One plot contained Douglas Fir seedlings, another Poplar cuttings, the third a grass mixture which soon became dominated by the reed canarygrass, and the fourth contained no vegetation. The results of the first two years of the project are indicated in Slide 24. The wastewater was secondarily treated effluent and about 400 lbs/acre-yr of nitrogen was applied in the 2 in/wk spray irrigation. The first year results for Poplar reflect the fact that the cuttings take a season to become established. Current results indicate the Poplar area improved to the point where the nitrate nitrogen in the soil solution averaged less than 1 mg/l for a renovation efficiency of greater than 90% for nitrogen. This is a higher level of renovation than even the reed canarygrass which had to be harvested four times per year. In the three years of the study, the Poplar grew high enough to become a valuable pulp and paper crop. Thus, young forests can compete with agronomic crops in renovation efficiency and entail much less work of an agricultural type.

What management techniques have been recommended to promote the success of forest lands as waste treatment sites (Slide 25)? Lines of perforated pipe operating at low pressure or low pressure sprinklers (Slide 26), just above the shrub layer are more effective than the high pressure nozzle type sprinklers which are more suited to low growing agronomic plants. Ditch irrigation, underground discharge pipes or other seepage distribution systems may warrant attention for forest lands. Ditches or trickling pipe systems could use low cost materials and low energy demanding pumps.

Excessive compaction of forest soil should be avoided if high infiltration/percolation rates are to be maintained (Slide 27). Excessive traffic by vehicles, humans, or cattle will compact soil as will any disturbance of the forest mulch.

Whole tree harvesting leads to increased nutrient removal from sites because most nutrients are in the crown of the trees (Slide 28). Removing the whole trees also prevents twigs, leaves, branches, and so forth from returning their stored nutrients to the soil (Slide 29).

Another management technique is to replace native tree species better suited to specific application schemes. A number of tree species under a variety of loading rates are recommended in Slide 30. This preliminary grouping was made according to the rate of tree height growth following two years of effluent irrigation.

It is important to know the tree species adaptability to the nature of the waste to be applied. Species adapted to moist, fertile conditions should prove more useful in renovation than species adapted to infertile, well drained soils.

A first step in planning wastewater treatment in forests is to determine species requirements. By doing this the planner can either adapt the wastewater application rate to the trees available or plant forests which are more suitable to higher rates of application.

Slide 31 shows the growth of cuttings and seedlings during the second growing season in a Michigan study. Note that growth of all species except red oak increased and that the best growth occurred at the highest irrigation rate of 5.5 centimeters per week. Note that, as with forage species, the shallow rooted species often found in moist soils are not necessarily the most tolerant to high irrigation rates.

Finally, the following three management techniques have been suggested: Multiple cropping, minirotation forestry, and explant production.

In multiple cropping schemes, trees and agronomic crops are grown together (Slide 32). Certain deciduous hardwoods may be more desirable for waste application on the basis of growth and nutrient absorption criteria. But hardwoods are unproductive in winter. Certain agronomic crops may be seeded under properly spaced trees at leaf fall and harvested annually by grazing or mechanical methods. Trees could be harvested at longer intervals depending on growth rate, or shade tolerant trees could be grown in the interrow area beneath deciduous trees for transplanting purposes. Multilayered arrangements may increase water handling capacity for a land unit and also enhance aesthetic appeal of the landscape.

In minirotation forestry, certain forest species which grow rapidly and produce fiber at an early age are planted at close spacing (Slide 33). They are harvested after two or three years like silage and the total above ground biomass is used for paper and other products. Coppicing, by allowing

regeneration of sprouts from the cut stumps, eliminates a number of costly replanting operations; each tree planting can provide about three coppice crops.

In explant production municipalities are supplied with entire trees of substantial size lifted with root ball intact (Slide 34). This scheme recognizes that environmentally aware citizens desire urban forests. In their tree, greenbelt, and flood plain ordinances, many cities are requiring that trees be not only protected but should be increased and optimally used. Wastewater is used to irrigate these trees raised in nurseries. Slide 35 shows ornamental shrubs and trees irrigated with wastewater at Belding, Michigan. Plant production in this manner even lifts a portion of the nutrient rich soil along with the tree roots. These operations show great promise not only because they yield marketable trees useful for maintaining urban forests but also because of total harvest with substantial nutrient removal.

This section of this module will turn to the application of wastewater and sludge to strip mined or deep coal mined acid spoil (Slide 36). With tighter federal and state regulations, reclamation is taking on increasing importance. With more attention focused on reclamation, the addition of sludge and wastewater to formerly mined areas may become a popular method of renovating the soil.

Municipal wastes tend to have a pH of about 6.8 to 7.2. In addition to their value as a source of water, they are high in dissolved nutrients, minerals, and organic matter that plants need (Slide 37). These are precisely the qualities which spoil bank material lacks.

At Pennsylvania State University in 1968 a series of studies were undertaken to determine if municipal sewage sludge and wastewater could be used to aid in the revegetation of spoil bank material. The results of one portion of the studies are shown in Slides 38 and 39. The first slide shows the control area, the second the area that received a combination of sludge and effluent. The results of their studies indicate that vegetative growth in several of the test plots was impressive. The best treatments for germination and growth included application of both sludge and effluent. The wastewater irrigation washed sludge solids off the plants, which prevented the foliage damage experienced by the plants receiving only sludge application. Slide 40 shows the growth of grasses on strip-mine spoils after two

different application regimes of combined sludge and municipal wastewater. These data are from a 1971 study at Penn State. In this case no vegetation would grow at all without the sludge amendments.

These Penn State studies are still going on, but they have already demonstrated that with proper site preparation and application of sludge and wastewater, highly acid strip mine spoil bank material can be revegetated. Revegetation is the crucial first step in reclaiming land, for without vegetation, there can be no stabilization of the piles of spoil material.

In the Shawnee National Forest in Illinois a demonstration site was established in 1970 to evaluate sludge application on strip-mined land. Anaerobically digested sludge from the Metropolitan Sanitary District of Greater Chicago was used. The studies indicated that sludge application on strip-mined soil must be at a high level in order to neutralize the acidity of the spoil and allow vegetation to grow. Slide 41 shows how the pH changed in sludge-amended spoil material. This treatment improved the spoil medium such that 90% vegetative cover developed by the end of the first year, whereas seed germination failed on the untreated spoil site. Slide 42 reports the concentrations of selected elements in percolating wastes on the site before and after sludge treatment.

It is evident from these results as well as from those obtained from Penn State that even though sludge may contain large amounts of potentially toxic elements and trace elements, such waste addition can actually cause the amount of some of these elements to decrease in the soil solution. All elements do not behave in the same way, and as Slide 42 indicates, the concentration of some elements may increase. These results suggest that leaching may result if the alkalinity of wastewaters alone is relied upon to neutralize acid mine spoils.

Other non-agricultural options for wastewater management are the irrigation of recreational areas, the creation of recreational lakes (Slide 43), and the formation of wildlife habitats.

As potable water becomes more expensive (Slide 44), a growing number of communities may elect to irrigate public landscaped areas such as parks, cemeteries, golf courses, green belts, and highway medians with treated

wastewater. The irrigation also provides additional treatment for the wastewater because it filters through the soil before discharge to surface water or groundwater. It has been estimated that freeway greenbelts in San Diego, California, require 45,000 gallons of water a day per mile (Slide 45). Wastewater irrigation of public green areas is already a common practice in the more arid regions of the Western United States. For instance, Colorado Springs, Colorado, uses treated effluent to irrigate a cemetery, four city parks (Slide 46), two golf courses, a college campus, and more than two acres of parkways. Golden Gate Park in San Francisco is perhaps the most well known park to be irrigated with treated effluent (Slides 47 and 48).

Many communities use secondarily treated effluent to irrigate golf courses as shown in this slide (Slide 49). Experience at the Ventura, California, golf course resulted in the recommendations shown in these slides (Slide 50).

Climate and site characteristics are fundamental in determining the amount of wastewater which may be applied to these recreational areas. Two inches of water a week during the growing season may be appropriate for many well drained sites in the Northeast. In California, one inch per week did not alter the composition of a chaparral plant community. Two inches of water a week allowed certain new species to grow. Three and a half inches per acre a week produced better growth.

Basic rules for creating and operating recreational areas using treated wastewater for irrigation are shown in Slide 51.

Experience has shown that it is possible for land treatment to alter water to the extent that it meets water quality standards for swimming and other contact sports. The Padre Dam Municipal Water District in Santee, California, allowed swimming in one of its seven recreational lakes which are all filled with treated wastewater (Slide 52). The lake met water quality standards for swimming set by the county, state, and federal health departments. However, the high level of chlorine in the water created a need for removal of iron and manganese. When the equipment for removing these two elements wore out, the water reclamation staff at Santee decided not to replace the equipment. After five years of successful use, swimming was discontinued at the Santee lake.

Each state establishes water quality standards for specific uses of that water. Designers of land application systems who plan to utilize the wastewater for recreational activities involving the water itself, be they contact or non-contact activities, should be aware of the local and state regulations and be prepared to meet these standards. These standards can be obtained from state health departments and pollution control agencies (Slide 53).

Rules to follow in managing a land application site which is also used for public recreation are shown in this slide (Slide 54).

A secondary benefit of many wastewater application sites is the attraction of wildlife (Slide 55). Many land application site operators have noted an influx of wildlife, particularly waterfowl such as ducks, geese, and grebes when water is allowed to accumulate in ponds and marshes.

As shown in this diagram (Slide 56), hedgerows may contribute to land application sites because they provide a habitat for wildlife, make the site more attractive to visitors, and help control water and wind erosion. They are also effective in blocking aerosol drift from spray irrigation.

Studies at Pennsylvania State University on responses of small mammals such as mice and rabbits and deer showed that wildlife was not adversely affected by land application of wastewater by spray irrigation. The wastewater in this study was chlorinated. The only significant difference noted was an increase in the body weight of young rabbits in the fall.

Using the land application site as a wildlife habitat can increase public acceptance of land treatment as long as reasonable safety rules are followed (Slide 57). The site may be used by nature lovers and educational groups. System operators may want to expand the wildlife population and to allow limited hunting. The recreational lakes at Santee are stocked with bass, pan fish, blue gill, sun fish and trout. This kind of facility may attract additional support for the land treatment alternative. A wildlife biologist, of course, should be consulted to evaluate the possibility of a desirable wildlife habitat.

With imagination and good management, a land treatment site can be an asset to a community aside from the fact that it treats the sewage (Slide 58). It can be used to improve forestland, reclaim acid mine spoils, and for recreation and wildlife (Slide 59). In planning any of these uses for wastewater or sludge, it is important that experts in the particular aspect are consulted (Slide 60). These experts can assess the waste and the local site and give recommendations that will raise the probability of a successful plan (Slide 61).